# Evaluation of Lake and Stream Acidification in Nine National Parks

February 2006

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**Report No. NPS D-1751**

## FOREWORD

The evaluation described in this document is not intended to provide a comprehensive assessment of lake and stream sensitivity to acidification in certain national parks. The evaluation was limited to waterbodies with available data and may not have included the most sensitive lakes and streams, which are often in high elevation areas with limited access. Rather, the evaluation was intended to test the utility of the Decision Support System (DSS) of the Air Quality Information Management System. This document describes the data requirements of the DSS that should be considered for future evaluations.

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The report can be downloaded from
http://www2.nature.nps.gov/air/Pubs/pdf/EvalAcidificationNineParks.pdf

# Chapter 1 - Introduction

The National Park Service (NPS) is responsible for protecting the lands and resources under its jurisdiction. Air pollution has the potential to affect these lands and resources, including water quality. The effects of pollution are a substantial concern because of the sizeable increase in pollution levels since the beginning of industrialization in the United States. For example, concentrations of anthropogenically-fixed nitrogen (N) measured in the early 1980's at Niwot Ridge in the Colorado Front Range were 30-fold greater than pre-industrial levels (Fahey et al., 1986). From 1850 to 1990, sulfur (S) emissions in North America increased almost 60-fold (Lefohn et al., 1999); more recently, regulations enacted under the Clean Air Act to combat acid rain have reduced S emissions significantly, and N emissions to a lesser degree.

N and S compounds enter the atmosphere from many sources, including automobiles and other transportation sources, power plants, industry, agriculture, and burning. In the U.S., about two-thirds of all sulfur dioxide ($SO_2$) and one-fourth of all nitrogen oxides ($NO_x$) come from electric power generation that relies on burning fossil fuels like coal. Automobiles, road transport, shipping, and aircraft are also significant sources of $NO_x$ emissions. Agricultural activities such as storage of manure, soil fertilizing, and animal husbandry emit N in the form of ammonia. These sources are increasingly significant contributors of atmospheric N. N and S compounds are transported and transformed in the atmosphere and eventually deposit into ecosystems as sulfates, nitrates, and ammonium compounds. In streams and lakes, these compounds can lead to acidification and eventual decline or loss of aquatic invertebrates, phytoplankton, and fish. In addition, the fertilizing effects of N can cause major changes in ecosystem structure and diversity by altering competitive interactions among organisms.

Streams and lakes vary in their sensitivity to acidification. High elevation aquatic ecosystems in the Rocky Mountains, Cascades, Sierra Nevada, and certain areas of the eastern U.S. are generally the most sensitive to atmospheric deposition due to their limited capacity to neutralize acid deposition.

The following report contains an evaluation of the sensitivity of certain lakes and streams in nine 'Class I' national parks to acidification by deposition of atmospheric S and N compounds. The first section of the report describes a decision support system (DSS) developed by NPS to evaluate the sensitivity of lakes and streams in nine parks in five regions of the country. The next section discusses the methods used for retrieving and processing water quality data for the evaluation. Subsequent sections provide overviews of pollutant emissions and their effect on water quality in the nine parks plus the results of running the processed data through the DSS and an interpretation of these results. Air and water quality overviews are provided for the New England, Pacific Northwest, Rocky Mountain, and Sierra Nevada regions.

The evaluation was undertaken not only to assess lake and stream sensitivity to acidification, but also to evaluate the utility of the DSS. The evaluation was limited by available water quality data obtained from the National Park Service's Baseline Water Quality Inventory and Analysis Reports (http://www.nature.nps.gov/water/horizon.cfm), which were generally completed in the 1990's. Often the reports did not contain all the data required for the DSS, or had data for a very limited (and not necessarily representative) number of waterbodies in a park. Lakes and streams thought to be most sensitive (high-elevation) are generally difficult to access and sampled infrequently, if at all. Therefore, some of the most sensitive waterbodies are not included in this analysis. Some of the data are over 30 years old and unlikely to reflect current conditions. The National Park Service has since undertaken a comprehensive water quality monitoring program at many national parks, and this more recent data should be considered when making management decisions.

Data from Rocky Mountain NP were processed by the DSS, but the analysis of the DSS output was not completed due to lack of available personnel time.

# Chapter 2 - Aquatic Chemistry Decision Support System

In 1994, the NPS began developing the Air Quality Information Management System (AQUIMS), designed to organize and archive air quality information for report generation and to provide decision support for resource management in parks. Within AQUIMS, NPS constructed a knowledge base to assist in identifying the status of the chemical condition of park waters. The information and systems in AQUIMS evolved into a more comprehensive information management system called "Synthesis," which has further evolved into a web-based system, the Air Resources Information System (ARIS).

The knowledge base, or expert system, is entitled the "Aquatic Chemistry Decision Support System" (DSS).

NPS developed the Aquatic Chemistry DSS using knowledge-engineering methodology with NetWeaver software. Its goal is to classify waters in five acid-sensitive regions of the United States, according to their sensitivity to acidification. The five regions are:

- Cascade Mountains
- Central Rocky Mountains
- Northeastern United States
- Northern Rocky Mountains
- Sierra Nevada

A panel of nationally recognized aquatic chemistry domain experts (including university and governmental scientists) participated in knowledge engineering sessions to develop the Aquatic Chemistry DSS. They identified the information needed for the water body classification, including water chemistry data and the criteria values for classification.

The Aquatic Chemistry DSS classifies water bodies into six categories based on sensitivity to acidic deposition, extent of impact from acidic deposition, and influence from other factors, including geologic sources of S, natural organic acidity, and the influence of disturbance and land use on water quality. Criteria values for classification vary among regions to reflect differences in historic S and N deposition loadings and likely changes in future deposition.

## Waterbody Categories

### Sensitive and Unimpacted

Sensitive but unimpacted waters have low buffering levels and are sensitive to acidification under continued or increased S or N deposition. There is no indication that the water body has acidified yet. Low acid neutralizing capacity (ANC), with low sulfate and nitrate concentrations, characterize such waters. Other indicators include low levels of organic matter and low to medium levels of specific conductance, pH, and base cations.

### Potentially Acid Deposition Impacted

Water bodies in this category appear to be impacted by acidic deposition. The classification is based on ANC plus information on pH and the concentrations of sulfate and nitrate. ANC is used preferentially over pH for classification; pH is not a good indicator of acidification until the lake has lost most of its ANC. In general, the lower the ANC (or pH), the greater the likelihood of acid deposition impact.

Other factors are also considered, including specific conductance and base cations. Low specific conductance suggests that the lake may be sensitive to, or has already been impacted by, acidic deposition; high specific conductance suggests that the lake may be "insensitive", exhibiting high buffering capacity, or that it may have been impacted by geological S. If either the ANC or pH is too low to have been the result of acidic deposition levels encountered in the region, then the low ANC and pH likely results from geological S. High ANC and, less reliably, high pH or base cation concentration suggest that the lake is insensitive. If sulfate concentration is very low, the lake is not likely to have been impacted, whereas if sulfate concentration is high, the lake is likely to have been impacted. However, if the sulfate concentration is very high, relative to expected concentrations for the region, based on levels of atmospheric input coupled with the concentration-enhancement effects of evapotranspiration, then much of the water's sulfate is likely not of atmospheric origin. In such cases, the acidity is more likely associated with geological sources of S.

High nitrate concentration suggests impact from deposition, but if the concentration of nitrate is very high, it is more likely associated with surface water runoff from agriculture or other land use activities, rather than acidic deposition. If dissolved organic carbon is high, then acid deposition is less likely to have caused acidification, and the low ANC and pH of the lake are more likely to have resulted from natural organic, rather than anthropogenic, acidity. Natural organic acids impart substantial buffering, and resist further acidification from acidic deposition.

## Natural Organic Acid Impacted

Lakes in this category are classified as natural organic acid impacted if they have high levels of organic material, as measured by high concentrations of dissolved organic carbon, and there is evidence that the high dissolved organic carbon appreciably contributed to low ANC and/or pH. Such conditions indicate that the lakes have substantial wetlands in their watershed and biota influences the water's chemistry more than any other factor.

## Insensitive to Acid Deposition

The DSS classifies lakes as insensitive to acidic deposition primarily on the basis of ANC. High ANC indicates that the lake is insensitive; low ANC suggests that the lake is not insensitive, but rather is sensitive but not yet impacted, or it is impacted by acidic deposition, geological S, or natural organic acidity. High concentrations of base cations or organic material, or a high specific conductance are also indicative of high buffering capacity.

## Geologic Sulfur Impacted

Lakes are classified by the DSS as geological sulfur impacted if water sulfate concentration is too high to be reasonably attributable to acidic deposition and if there is evidence that the high sulfate concentration has appreciably altered the water acid-base chemistry by causing low ANC and/or pH. Mine drainage is one source of geological S. The higher the concentration of sulfate in water, the greater is the likelihood that much of the sulfate is of geological, rather than atmospheric, origin. However, high sulfate levels without low values of pH and ANC are not sufficient to classify a lake as geologic S impacted. In addition, the DSS recognizes that lakes that are close to the coast are likely to have higher concentrations of sulfate than inland lakes; the high sulfate does not indicate a geological S influence, but rather a marine influence.

## Disturbance/Land Use Impacted

Lakes categorized as disturbance/land use impacted have impacts associated with watershed disturbance or land use. In particular, the DSS identifies lakes that have been impacted by high nitrate concentration as a consequence of agricultural activities, forestry, or other land use in the watershed. The DSS does not attempt to identify other impacts, such as severe insect defoliation.

# Values

The DSS produces a numerical value for each category corresponding to its trueness for each site based on the input data. The value is a number from -1 to 1. Table 2-1 shows the meaning of the value for each category.

**Table 2-1: Value Interpretations**

| Value | Meaning |
|---|---|
| -1.00 | This category is untrue for this site |
| -0.99 to -0.01 | This category may be untrue for this site. The lower the number, the greater certainty that the category is untrue |
| 0.00 | There is no certainty about the trueness of this category |
| 0.01 to 0.99 | This category may be true for this site. The higher the number, the greater certainty that the category is true |
| 1.00 | This category is true for this site |

The individual values were categorized into an arbitrary set of ranges selected to facilitate discussion of the DSS results. Table 2-2 lists a level of certainty defined by ranges of result values.

**Table 2-2: DSS Value Ranges**

| Range | Meaning |
|---|---|
| -1.00 to -0.60 | It is almost absolutely certain this category is untrue |
| -0.59 to -0.20 | It is fairly certain this category is untrue |
| -0.19 to 0.20 | No certainty |
| 0.21 to 0.60 | It is fairly certain this category is true |
| 0.61 to 1.00 | It is almost absolutely certain this category is true |

## Regional Variation

The DSS structure varied from region to region, in response to observed differences in regional water chemistry, which are partly due to different regional histories of atmospheric S and N deposition. The northeast region was tested using data from the Eastern Lakes Survey, Adirondack Mountains and Maine subregions, and additional lake data from Maine. Each of the four western regions was tested with data derived from the Western Lakes Survey and a group of acid-sensitive waters modeled with the Model of Acidification of Groundwater in Catchments (MAGIC). Each region was adjusted in structure and in terms of decision criteria values until it consistently represented both the expert judgment regarding lake classification and the perceived uncertainty inherent in that classification judgment.

Figure 2-1 gives examples of how the DSS interprets a given parameter in a given category on a region-by-region basis. In the northeast region, an ANC value less than 45 microequivalents per liter (μeq/L) results in a value of false (-1) in the 'Insensitive to Acid' category. If the ANC value is greater than 100 μeq/L in this region, it results in a value of true (1) in this category. An ANC value greater than 45 μeq/L and less than 100 μeq/L will return a value between -1 and 1, with the most uncertain value being half-way between 45 and 100, or 72.5. The value for this parameter is logically combined with other parameter values as deemed appropriate by the subject-matter experts for the 'Insensitive to Acid' category to determine the final value for the category.

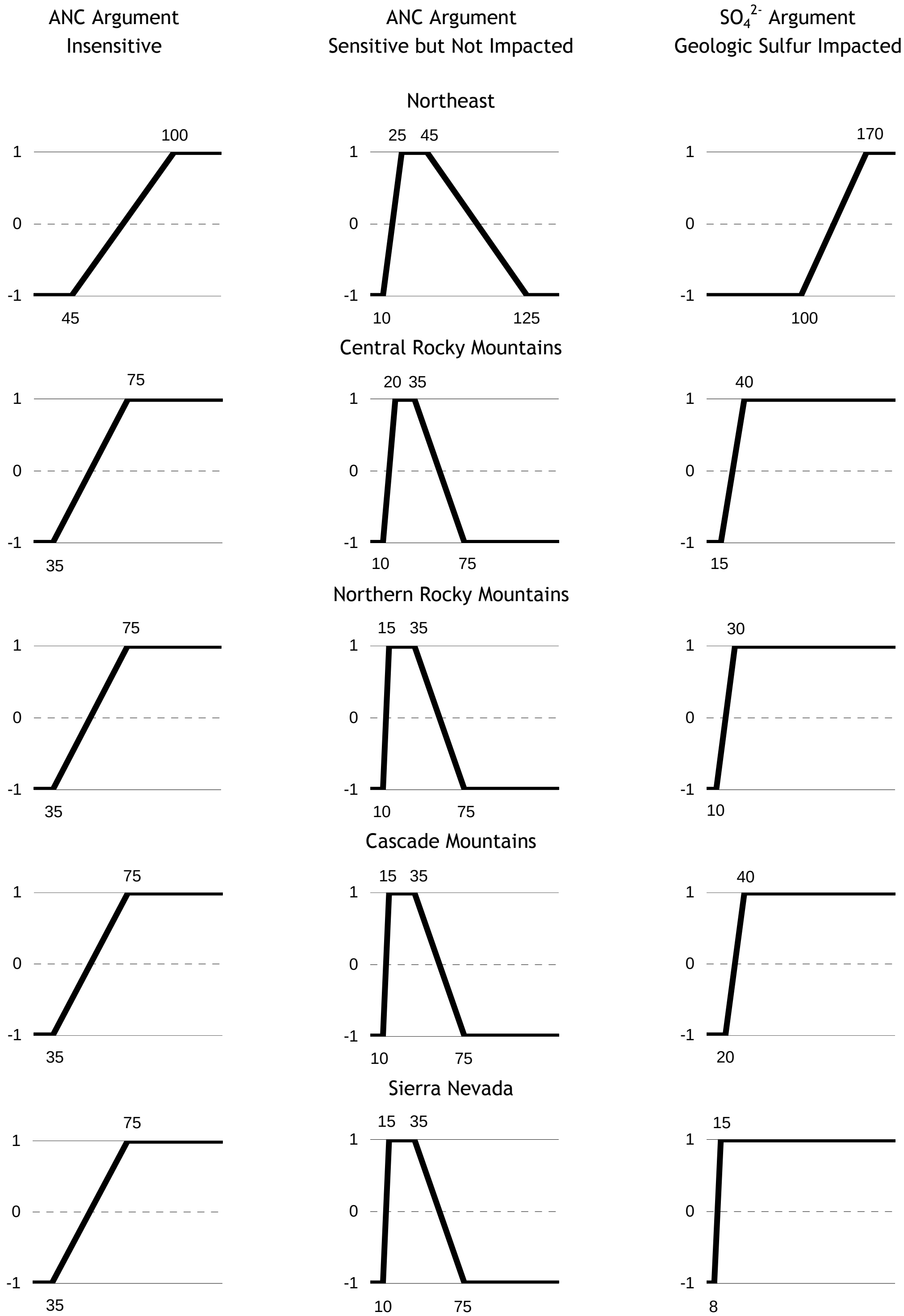
Regional variation allows equal values for a parameter to mean different things across regions. For example, in the northeast region, an ANC value of 80 μeq/L would result in a degree of uncertainty in the ‘Insensitive to Acid’ category (a value less than 1) but would equal a value of true (1) in all of the other regions. This reflects the need of a higher buffering capacity keep water insensitive to future acidic episodes in the northeast, due to the effects of acid rain compared to the cleaner air over western mountain regions.

In the northeast, an ANC value of less than 10 μeq/L results in a value of false (-1) in the ‘Sensitive but Not Impacted’ category. Waters with such low ANC values are deemed to already have been impacted. ANC values between 10 and 25 μeq/L result in a value between -1 and 1, meaning that the DSS is uncertain as to whether to ANC is low enough to signal impaction. ANCs between 25 and 45 μeq/L return a value of true (1) in this category. If other parameters for this water body indicate it is not acidic, the water will be found to be sensitive to future acid increases but not yet impacted. ANCs between 45 and 125 μeq/L result in uncertainty as to whether the ANC is high enough for the water to be considered insensitive to acid. ANCs above 125 μeq/L return a false value (-1), indicating that the water is insensitive to acid.

A sulfate ($SO_4^{2-}$) value of less than 100 μeq/L results in a value of false (-1) for the ‘Geologic Sulfur Impacted’ category in the northeast. A sulfate value greater than 170 μeq/L results in a value of true. These values are substantially higher in the northeast region than the western mountain regions due to this region’s proximity to the ocean, historically higher sulfate concentrations in atmospheric deposition, and greater evapotranspiration. Near-coastal waters receive atmospheric deposition of marine aerosols, which contain appreciable concentrations of sulfate derived from seawater (Sullivan et al. in review).

However, this is not the sole criterion of the rating for the ‘Geologic Sulfur Impacted’ category. The DSS decides its rating for this category based on ANC, specific conductance, DOC, pH, and the sum of base cations. Thus, Figure 2-1 shows only part of the criteria for classification.

**Figure 2-1: Schematic illustration of three DSS arguments within each of the study regions. The arguments selected for illustration are: (1) ANC arguments for 'Insensitive to Acid' waters, (2) ANC arguments for 'Sensitive but Not Impacted' waters, and (3) sulfate ($SO_4^{2-}$) arguments for 'Geologic Sulfur Impacted' waters. Values range from -1 (false) to +1 (true). Source: Sullivan et al, in review.**



## Data Requirements

The water quality data used in the Aquatic Chemistry DSS to classify lakes in parks comes from the NPS Baseline Water Quality and Analysis Reports. Because Horizon Systems Corporation in conjunction with NPS's Servicewide Inventory and Monitoring Program and the NPS's Water Resources Division (WRD) gathered the data, these reports are known as Horizon reports. The goal of these reports is “to provide descriptive water quality information in a format useable for park planning purposes.” The data in the Horizon reports was obtained from the Environmental Protection Agency’s STORET (STOrage and RETrieval) system. The Horizon reports are available from the National Park Service Water Resources Division at http://www.nature.nps.gov/water/horizon.cfm.

The data extracted from the Horizon reports is summary data, including both mean values and extreme values. Conclusions drawn from using the mean data are likely to underestimate the extent of problems such as acid mine drainage impacts or acid rain impacts. One possible way to bracket the true situation regarding impacts is by using a worst-case combination of the extreme values. This worst-case combination would include a site’s lowest values for parameters that measure the protection of the water from impact (ANC, sum of base cations, and specific conductance) and its highest values for parameters that contribute to acidification (sulfate, nitrate, and DOC). The worst-case combination would also include minimum pH values, an indication of acidity, and minimum chloride values, to report the lowest fraction of sulfate may have come from neutral sea spray as opposed to sulfuric acid.

A number of water chemistry parameters are required for the Aquatic Chemistry DSS. These parameters are closely associated with acid-sensitivity. In general, acid-sensitive waters have specific conductance below 25 μmhos/cm, acid neutralizing capacity (ANC) below 100 μeq/L for episodic acidification (50 μeq/L for chronic acidification), total base cations (calcium, magnesium, sodium, and potassium) concentration below 100 μeq/L, and a pH below 6.0. There are exceptions to this, depending on geology and other factors. Therefore, the DSS considers other parameters in addition to ANC, total base cations, and pH.

### Water Chemistry Parameters

As mentioned above, an expert panel determined which water chemistry data to include in the DSS. Table 2-3 lists the seven parameters decided upon.

**Table 2-3: Required Water Chemistry Data for Aquatic Chemistry Decision Support System (DSS)**

| Data types | Meaning |
|---|---|
| ANC | Acid neutralizing capacity (microequivalents per liter = μeq/L) |
| $SO_4^{2-}$ | Sulfate concentration (μeq/L) |
| $NO_3^-$ | Nitrate concentration (μeq/L) |
| DOC | Dissolved organic carbon (milligrams per liter = mg/L) |
| Conductivity | Specific conductance (microSiemens per centimeter at 25 degrees Celsius = |

| | |
|---|---|
| | μS/cm@25C) |
| pH | Water pH |
| Sum of base cations | Sum of potassium ($K^+$), magnesium ($Mg^{2+}$), calcium ($Ca^{2+}$), and sodium ($Na^+$) concentrations (μeq/L) |

In addition to the water chemistry parameters, other location-related parameters are extracted from the Horizon reports. Site number, agency code, STORET ID, and location identify the data, in case it is necessary to go back and look at the data in the reports. Data such as the period of record and the number of observations are used to gain a sense of how much confidence can be expressed in the data at a location. Other values, such as temperature and chloride and fluoride concentrations, are used to further assess waters that are on the borderline in categories.

Below is a list of the data extracted from the Horizon reports and recorded in the spreadsheets and a brief description.

*Site Number*

The recorded site number is a simplified version of the 8-digit site number found on the Horizon report. In the report, the number is the 4-digit park code followed by the four-digit site number. In the spreadsheet, the site number is the four-digit site number without any leading zeros. For example, site NOCA0042 in the Horizon report becomes site number 42.

*Agency Code and STORET ID*

These codes enable retrieval of the Horizon report from STORET. STORET (short for STOrage and RETrieval) is a repository for water quality, biological, and physical data and used by state environmental agencies, federal agencies, universities, and private citizens.

*Location*

This field records the name of the location of the water sample. The Horizon reports provide latitudinal and longitudinal coordinate points, but the DSS does not use them so they are not recorded.

*Sample Type*

There are seven basic sample types: lakes and reservoirs, streams, springs, oceans, estuaries, wetlands, and canals. The DSS handles aquatic chemistry data for lakes and streams only. These two sample types make up 90% of all of the water locations identified in the Horizon reports for the 9 parks in the study. The values in this column serve to separate the data into lake and stream data prior to running the DSS.

*Period of Record*

The period of record indicates the first and last sampling dates for a location. The DSS is not time sensitive. However, recording the period of record allows for an analysis of the age of the data.

*Number of Observations*

This column captures the number of observations of any water quality parameter at the site. This data assists in analyzing the frequency of sampling at a particular location and throughout the park.

*Depth of Water*

Eepth measurements pertain almost exclusively to lakes. This value is not used in Synthesis, but serves as a reminder that the samples taken and reported on in the reports are from the lake surface. A lake's water chemistry may be radically different at different depths, especially if the lake is seasonally stratified.

*Temperature*

Temperature is generally in degrees Centigrade. However, at some sites, the temperature measurements are in Fahrenheit. These sites have the temperature marked in bold. In either case, the mean temperature value is recorded.

*Specific Conductance*

Conductivity is a measure of the ability of water to pass an electrical current. The presence of inorganic dissolved solids such as chloride, nitrate, and sulfate anions (negatively charged ions) or sodium, magnesium, calcium, and potassium cations (positively charged ions) affects conductivity in water. The DSS uses specific conductance as an indication of buffering capacity. Higher values indicate greater ionic concentration in the water and in general, greater buffering capacity. For this reason, the spreadsheet records the mean and the minimum values of specific conductance. This is to give a general idea of the effect of specific conductance on average and at its most extreme.

Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Temperature also affects conductivity: the warmer the water, the higher the conductivity (USEPA, 1997).

The units for specific conductance are microSiemens per centimeter at 25 degrees Celsius ($\mu$S/cm@25C). Specific conductance data in the Horizon report use units of micromhos per centimeter ($\mu$mho/cm), which is equivalent to the newer unit of microSiemens per centimeter. Field measurements of specific conductance were used for the DSS preferentially over laboratory measurements.

*pH*

The pH value is a measure of acidity and is an important parameter in the DSS. Whenever possible, a field value of pH is used. The spreadsheet contains both the mean and the minimum value (highest acidity) to give an idea of the effect of pH on average and at its most extreme.

*Alkalinity and ANC*

ANC is derived from various alkalinity measurements or, in rare cases, is measured directly. It is used as a basis for determining the impact of acid deposition on a water body as well as the resistance of that water body to future acid deposition. The DSS uses the ANC value. Both the mean and minimum values are recorded to determine the effect of ANC on average and at its most extreme.

Alkalinity is generally measured in two ways: total alkalinity (milligrams per liter - mg/L as $CaCO_3$), or total low level Gran analysis. The total alkalinity value is converted to μeq/L before it is entered in the ANC (Acid Neutralizing Capacity) column. The units of total low level Gran analysis are μeq/L; thus, this value is placed directly in the 'ANC' column. In some cases, a sample's alkalinity was measured using two color indicators of the endpoint of an acid/base titration, methyl orange and phenolphthalein. The endpoint measurements are converted to μeq/L using the same conversion as a total alkalinity measurement; their values are totaled and entered in the total alkalinity column in the spreadsheet. The total alkalinity measurement is the preferred measurement over the addition of methyl orange and phenolphthalein measurements.

*Dissolved Organic Carbon (DOC)*

The DSS determines the impact of natural organic acid by evaluating dissolved organic carbon concentrations. High organic acid levels may lower a waters pH. Some waters may be naturally acidic; the DSS uses the DOC measurement to distinguish these systems from waters impacted by anthropogenic factors. Both the mean and maximum values are recorded to see the effect of DOC on average and at its most extreme.

*Nitrate*

The DSS uses the microequivalent nitrate ($NO_3^-$) concentration as a measure of the effect of acid deposition on a body of water. $NO_3^-$ is highly soluble in water and is stable over a wide range of environmental conditions. Higher values indicate greater acidic or land use effect. For this reason, the mean and maximum values of nitrate are taken to determine the effect of nitrate nitrogen on average and at its most extreme.

Nitrate measurements may be derived from one of three measurements in the Horizon Reports:

- $NO_3^-$
- $NO_3^-$ as N (nitrate nitrogen as N)
- $NO_3NO_2$ (nitrate plus nitrite - $NO_2^-$)

'$NO_3$' or '$NO_3$ as N' are the preferred values. They measure only the effect of nitrate. For use in the DSS, the nitrate concentration is expressed in μeq/L. If values exist for both '$NO_3$' and '$NO_3$ as N', the higher value of the two is used. If both are absent, '$NO_3NO_2$' is an acceptable substitute, as the concentration of nitrite nitrogen is generally small enough to ignore. $NO_2^-$ is relatively short-lived in water because it is quickly converted to nitrate by bacteria. The $NO_3NO_2$ concentration is also expressed as μeq/L.

The reports contain additional measurements of N:

- Ammonia as N ($NH_3$ as N)
- Ammonium ion ($NH_4^+$)
- Kjeldahl N (ammonia plus organic N)
- Total N

The DSS does not use the additional N values; however, the mean values are recorded and consulted when making a decision on the degree of impact on borderline parks.

### *The Base Cations: Calcium, Magnesium, Sodium, and Potassium*

Concentrations of calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), sodium ($Na^+$), and potassium ($K^+$), are measured in mg/L. In some locations, the calcium concentration is expressed as calcium carbonate ($CaCO_3$). Together, these four elements make up the base cations. They are a measure of resistance of the water to acid deposition. These values are converted to μeq/L and summed to find the sum of base cations (SBC) for the DSS. Because they are a measure of protection against acid deposition, the mean and minimum values are recorded to determine the effect of the SBC on average and at its most extreme.

All of the base cation components were not measured at some locations. Not having data for any component will underestimate the true value of 'sum of base cations'. For a given park the ratio of Ca to Mg, Na to K, and (Ca + Mg) to (Na + K) are fairly constant. Thus, it is possible to calculate these ratios from sites with complete data and apply it to those with missing data. The calculation of each ratio involves all locations with complete data in a park.

### *Chloride and Fluoride*

Chloride ($Cl^-$) and fluoride ($F^-$) concentrations are used to evaluate borderline sites, especially those near coastal areas. The fluoride measurement is not used directly by the DSS. While chloride is not used in all of the regional knowledge bases, it is used for coastal locations to estimate what fraction of sulfate may have come from neutral sea spray as opposed to sulfuric acid. Both the mean and minimum values are recorded to see the effect of chloride on average and at its most extreme, while only the average level of fluoride is captured.

*Sulfate*

Sulfate measurements ($SO_4^{2-}$ or $SO_4^{2-}$ as/S) help to determine the effect of acid deposition and the impact of geologic S on a site. Because higher values indicate a greater impact, the mean and maximum values are recorded to see the effect of sulfate on average and at its most extreme.

## Missing Data

If some of the data used by the classification algorithms in the DSS are missing, the DSS reports less confidence in the classification. As progressively more variables are missing from the data set, there is progressively less confidence in the results (Sullivan et al., in review). In addition to generating values for the six categories, the DSS reports a classification concerning insufficient data in the data set. Obviously, more missing data results in a greater level of certainty that the data set is incomplete. Resource managers may choose to collect additional data to increase confidence in the classification results.

## Data Limitations

Since the DSS uses statistical summaries of the data, the DSS results only distinguish between parks that clearly have no problem and those parks that clearly do or that may have problems. For some sites in some parks, it may be advisable to process data for individual samples through the DSS.

For each park there are a number of water quality sampling sites. Multiple agencies, including NPS and the U.S. Geological Survey, took these samples. Sampling occurred at varying times of year and in different years. As a result, each site has varying amounts of data, depending upon the tests on the water performed for that site.

The method of data collection varied from site to site, and the number and location of sites may not be representative of the entire park. Because the most acid-sensitive lakes are likely to be in very high elevation areas, they tend to be remote and difficult to access. **The report may not contain data for the most sensitive lakes; therefore, the analysis does not give a true representation of the extent or severity of impact by acid deposition for the entire park.**

Of the 2953 sample locations identified in the Horizon reports for the nine parks in this analysis, 21% of them had no data for any of the parameters used by the DSS.

Another 27% had one or two of these parameters. Only 5% of locations had all of the parameters used by the DSS. When the DSS does not have enough data to make a decision, it places a high degree of uncertainty on that site. It is difficult to come to any conclusions about locations that have such uncertainty.

Another issue concerns the infrequency of sampling. Often, sampling occurred frequently at a location for temperature but infrequently for other parameters. Many results contain data from one or two samples. For example, of the 1200 locations that contain alkalinity data, 60% of them contain only one measurement. In these cases, the result is 'extreme' values that are the same as the mean values. Therefore, in many instances, the analysis with extreme water chemistry values is nearly or exactly the same as the analysis with mean water chemistry values. Only 6% of all alkalinity results were the result of more than 10 sample tests. With so few samples, it is difficult to ascertain if the data assembled is representative of the water body in question. Further sampling is necessary in most locations to gain a true sense of a location's water chemistry.

Of the seven water quality parameters used by the DDS, data for pH and specific conductance are most abundant. Of the 2338 locations that have one or more data elements used by the DSS, 84% have pH data and 87% have specific conductance data. These data have a greater frequency of collection because most times those collecting the sample perform these measurements in the field.

Data concerning ANC, and nitrate, sulfate, and base cation concentrations is relatively abundant. ANC data was available at 52% of sites with data, nitrate data at 65%, sulfate data at 51%, and base cation data at 56%.

Dissolved organic carbon is the least available parameter. Only 10% of all locations with data contain DOC measurements. The lack of DOC data is more prevalent for samples taken before 1980. In the DSS, this leads to a finding of uncertain for most locations in terms of the Natural Organic Acid Impacted category.

Information is more complete for lakes than for streams. Of the 746 lakes in the parks included in this evaluation, 94% have at least one data component used by the DSS, as compared to 76% of the 1912 streams. Both lake and stream data are moderately complete, with 45% of lakes and 40% of streams with data containing 6 or 7 data elements used by the DSS.

Much of the data contained in the Horizon reports reviewed for this analysis is historical data. Some of the reports were issued up to a decade ago. Sampling occurred at most of these locations in the 1970s and 1980s. In fact, of the 2620 locations that have recorded data, 77% were sampled before 1990, and 51% were sampled before 1980. The last samples from a few locations came from the 1930s. The condition of these waters has probably changed over the past 15 years, much less over 20 to 30 years. Even if the location has enough data to input into the DSS to make an assessment with some certainty, it is unlikely that assessment reflects the current conditions at that location. However, the National Park Service continues to improve the quality of water chemistry information for parks, with enhanced water quality monitoring and data management.

## Locations

As mentioned above, the DSS classifies lakes in five acid-sensitive regions of the United States according to their sensitivity to acidification. Each region has its own unique calibration within the DSS to take into account distinct factors within the region.

NPS administers 48 "Class I" areas; this analysis looks at nine "Class I" national parks. Class I areas were designated by the Clean Air Act amendments of 1977 and include national parks over 6,000 acres and national wilderness areas over 5,000 acres that were in existence before August of 1977. The nine parks, and their park codes, are listed below.

| | |
|---|---|
| • Acadia (ACAD) | • Rocky Mountain (ROMO) |
| • Grand Teton (GRTE) | • Sequoia/Kings Canyon (SEKI) |
| • Mount Rainier (MORA) | • Yellowstone (YELL) |
| • North Cascades (NOCA) | • Yosemite (YOSE) |
| • Olympic (OLYM) | |

For this report, parks are grouped by their acid-sensitive region. Each section provides an introduction to the air and water quality in the region, followed by an introduction and the DSS results for the individual parks in that region. Table 2-4 lists the parks by their region.

**Table 2-4: Included Parks by Region**

| Acid-sensitive Region | Park |
|---|---|
| Cascade Mountains | Mount Rainier, North Cascades, Olympic |
| Central Rocky Mountains | Rocky Mountain |
| Northeastern U.S. | Acadia |
| Northern Rocky Mountains | Grand Teton, Yellowstone* |
| Sierra Nevada | Sequoia, Yosemite |

*The analysis intended to include Glacier National Park (GLAC), a Class I park in the Northern Rocky Mountains region. However, a Horizon report had not yet been done for GLAC at the time of this analysis.

# Chapter 3 – Air and Water Quality in the New England Region

The information in this section was obtained from a document entitled "New England's Changing Climate, Weather, and Air Quality Climate" produced by the Change Research Center at the University of New Hampshire in 1998. This document is available on the Internet at http://www.neci.sr.unh.edu/neccwaq.html. This section is not meant to be a complete discussion of air and water quality in the New England Region nor a complete bibliography. Instead it provides an introduction to some of the environmental factors that are thought to most influence the lakes and streams described in this chapter. Some of the sources of emissions discussed here have changed greatly during the time that the data on the region's lakes and streams were collected and likely will continue to change as a result of emissions controls. Similarly, additional research continues in the region and improves our ability to understand the changes in the chemistry of lakes and streams.

## Environmental Setting

The Atlantic Northeast contains land of bare rock, thin soils, rugged coastlines, swift streams, and slow-growing forests. Natural forces have contributed greatly to the present-day geography of this region. Mountains and hills consisting of hard crystalline rock were scoured by ice sheets that receded from the region 10,000 years ago. When the ice receded, it left thin soils and an undulating surface favorable for fast-running streams and bright, clear lakes.

New England regional weather and climate are highly variable. This holds true at time scales of from days to weeks, years to decades, and thousands to millions of years. Regional variability includes extremes of both hot and cold temperatures, droughts, heavy rainfall, hurricanes, tornadoes, blizzards, and more. Such variations in New England regional weather are influenced by many factors which relate to the region's physical geographic setting, including its latitude and coastal orientation, its topographic variability, and its position relative to the North American continent and prevailing storm tracks.

## Air Quality

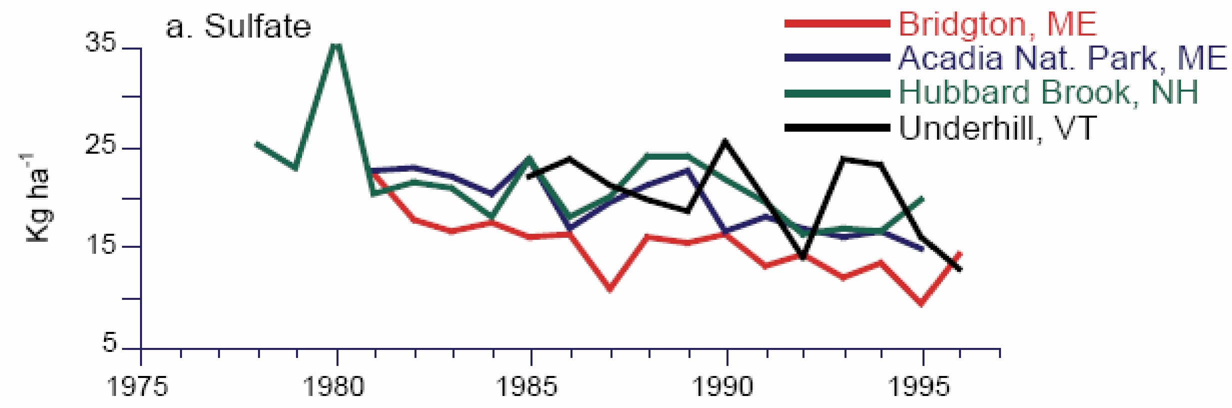
Certain New England aquatic and terrestrial ecosystems have been impacted by acid rain. This is largely the result of the influx of airborne pollutants originating from industrial regions, metropolitan centers, and transportation corridors located in upwind source regions (especially in the Midwestern and mid-Atlantic United States). Emissions from within northern New England from transportation and industrial sources also play a key role.

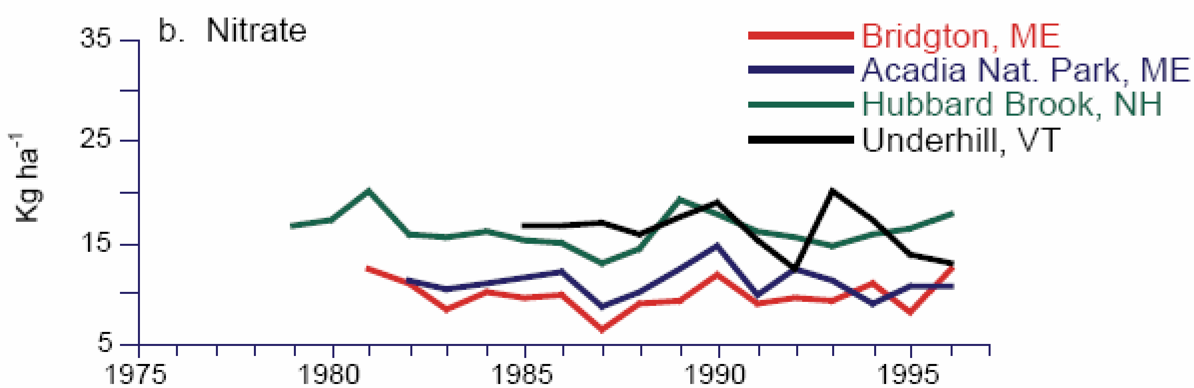
Acid rain is caused primarily by the emission of sulfur dioxide ($SO_2$) and nitrogen oxides ($NO_X$) from the combustion of fossil fuels in power plants, automobiles, and other sources. In the Northeast, this phenomenon has caused lakes and stream to become unsuitable for many fish (Baker and Schofield, 1985; Park, 1987). Acid rain has been known to leach heavy metals such as mercury from rocks, thereby causing contamination of water supplies and introducing human health risks (Brakke et al., 1988). Acid rain can also alter soil chemistry in agricultural and forested lands and causes significant damage to human made structures, especially those consisting of limestone and marble. In addition to contributing to acid rain, sulfate aerosols also play a significant role in Earth's radiation balance. The increase in sulfate aerosol in the troposphere adjacent to industrial regions of the globe over the past century has in fact served to cool climate on a regional scale (Charlson et al., 1992; Mayewski et al., 1993, IPCC, 1995).

Marine air masses (those coming from the east) show high levels of sea salt (composed primarily of sodium and chloride); air-masses from the eastern seaboard south of New England show high levels of acidic species, indicative of anthropogenic emissions from the burning of fossil fuels in the mid-Atlantic states; and air-masses from Canada show very low sea-salt, indicative of their continental origin. Air masses from the northwest (i.e., those originating in Canada) also show high levels of ammonium, likely reflecting agricultural sources from rural areas to the northwest of New Hampshire's seacoast (Lefer, 1997).

Aerosol chemistry samples from Whiteface Mountain in upstate New York show a strong correlation between the decrease in $SO_2$ emissions in the mid-western states since 1970 and the decrease in average sulfate concentrations in the Northeast (Husain et al., 1998). The deposition of sulfate in precipitation in northern New England measured at four locations has decreased on the order of 30% since the early 1980s (Figure 3-1a). The deposition of nitrate has shown no significant change since the early 1980s (Figure 3-1b).

**Figure 3-1: Annual average (a) sulfate and (b) nitrate deposition (kilograms of sulfate or nitrate per hectare) measured in precipitation at four National Atmospheric Deposition Program (NADP) sampling stations in northern New England.**




The decrease in sulfate deposition and precipitation acidity can be directly linked to the reduction in $SO_2$ emissions as a result of the Clean Air Act. Annual $SO_2$ emissions from anthropogenic sources in the U.S. have decreased from 28.3 million metric tons in 1970 to 17.4 million metric tons in 1996. At the same time, nitrogen oxides emission rates have increased from 19.7 million metric tons in 1970 to 21.3 million metric tons in 1996.

## Lake and Stream Chemistry

Bedrock geology controls the natural quality of surface waters in the study area. The presence of weather-resistant igneous and metamorphic rock units and thin soils results in surface waters that naturally contain low concentrations of dissolved and suspended solids. Rainwater (1962) notes that surface waters in New England contain less than 100 mg/L of dissolved solids and 275 mg/L of and suspended solids; these amounts are small compared to waters nationally. Calcium and magnesium ions are the prevalent cations in New England waters (Rainwater, 1962). Carbonate-bicarbonate anions are the principal anions in waters found in the high altitudes and sulfate and chloride anions are the principal anions in waters near the Atlantic Coast.

Alkalinity generally is low in the highest elevations and high in valleys having agricultural and urban lands. Most streams have alkalinity values less than 200 μeq/L (Griffith and Omernik, 1988). In comparison to other areas of the Eastern United States, Hendrey et al. (1980) found that the New England Coastal Basins are underlain by large amounts of bedrock with low to no buffering capacity. As a result, the surface waters of the study area are highly susceptible to acidification by acidic precipitation.

The influence of human activities on streamwater quality varies from the headwaters or upstream sections of the major river basins to the outlets of the rivers near their discharge to coastal waters. Human population is generally greatest near the coast and, as a result, water-quality and habitat degradation is more pronounced. The discharge of raw sewage from population centers and wastes from tanneries, textile, and pulp and paper mills was pervasive early in the 20th century. River water quality has improved throughout New England since the passage of the Federal Water Pollution Control Act in 1972 (U.S. Environmental Protection Agency, 1995).

The chemistry of surface waters in the Hubbard Brook Experimental Forest (HBEF), White Mountain National Forest, New Hampshire, has been studied extensively since the early 1960s and the conclusions are summarized by Likens and Bormann (1995). HBEF streams are acidic (pH of 4-5) because of the dominating presence of sulfuric and nitric acids from precipitation. Geochemical-weathering reactions neutralize the acids and bicarbonate alkalinity increases as water travels through the watersheds. Likens and Bormann (1995) found that even though there are steep slopes and high precipitation rates, erosion and transport of suspended (particulate) matter from forested watersheds is relatively low.

Research performed at the HBEF since the 1960s has described the effects of both atmospheric deposition and silvicultural activities on the hydrology of small headwater basins in environmental settings that are common in the northern part of the study area (Likens and Bormann, 1995; Likens, 1985). The changing chemistry of streams in the HBEF closely mimics the change in precipitation chemistry from the combustion of fossil fuel and industrial processes (Likens and Bormann, 1995). During 1963-93, hydrogen ion and sulfate concentration in HBEF streams decreased as sulfate emissions have decreased. Even with these decreases, sulfate deposition is more than three times the amount that the watershed can neutralize (Likens and Bormann, 1995). Because of the inadequate buffering ability of HBEF streams to neutralize acids, the acidity of streams has increased. Other effects of atmospheric deposition include depletion of calcium from the watersheds, which has been linked to declines in northern forest growth (Likens and Bormann, 1995), and nitrogen enrichment of surface waters that can lead to eutrophication of coastal waters (Jaworski et al., 1997). Jaworski et al. (1997) estimated that about 64% of the total nitrogen exported to coastal waters from 10 basins in the Northeastern United States was due to nitrogen-oxide emissions from fossil fuel combustion. Nitrate fluxes from these basins increased 300-800 percent since the early 1900s and correlate to increases in nitrogen-oxide emissions.

Other sources of contamination in the study area are the introduction of chloride and sodium to wells from road-salting and elevated concentrations of nitrates from agricultural activities and on-site septic systems. Concentrations of chloride in many New Hampshire public-supply wells in urban areas have increased significantly since the 1940's when the use of salt to de-ice roads greatly increased (Hall, 1975). Contamination from road-salt storage piles and facilities and spreading of salts on roadways was the cause of 79% of the contaminated wells in New Hampshire (Morrissey, 1988). Sodium chloride from seawater intrusion, coastal flooding, and high-water deicing salt is the most common cause for elevated concentrations of dissolved solids in ground water on Cape Cod (Frimpter and Gay, 1979).

# Chapter 4 - Acadia National Park

## Background

Much of the information in this section was obtained from a document entitled "Acadia National Park Long-Term Ambient Air Quality and Air Pollution Effects Monitoring and Research Strategy".

### Description

Acadia National Park (NP), designated in 1929, is located along the mid-coast of Maine and is the only National Park in the northeastern United States (the National Park Service administers additional sites in the Northeast, including national historic sites. With more than 40,000 acres it is one of the largest publicly owned and protected natural areas in the region. Park owned lands are scattered across more than a dozen islands and a portion of the mainland on the Schoodic peninsula. In addition, the park has responsibility for administering approximately 160 conservation easements on more than ten thousand acres of privately owned lands within the Acadian archipelago.

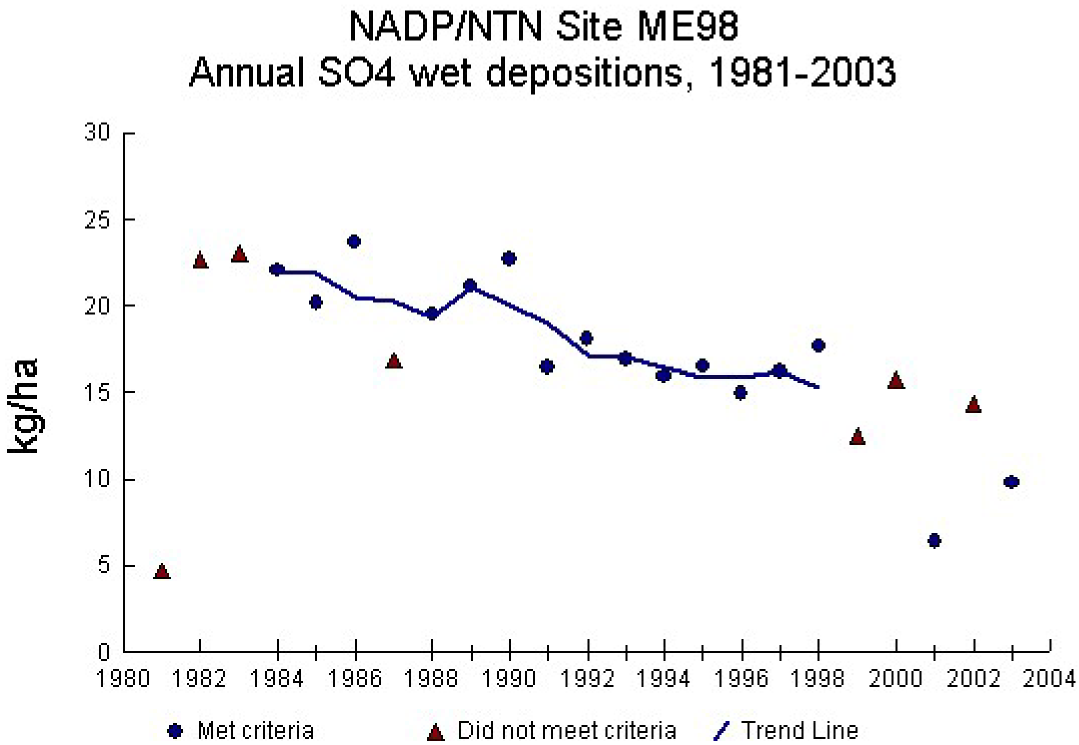
The weather in Acadia National Park is moderate compared to the rest of northern New England. Frequent thawing periods prevent large, long-term snow accumulations. Ice storms are common in winter and early spring, and rain occurs in every month. Fog is also a frequent phenomenon at the park that tends to peak in June, tapering off in winter. Northeastern storms, occurring mainly in late fall and winter, are generally severe windstorms. Hurricanes occasionally pass through the region.

### Deposition

Primarily as a result of long-range transport by prevailing winds, Acadia NP periodically experiences high concentrations of a variety of air pollutants. Located along the mid-coast, the park is downwind from large urban and industrial areas in states to the south and west.

A NADP/NTN site was installed at McFarland Hill, in Acadia NP, in November 1981 (site ME98, elevation of 499 feet (152 m)). In agreement with the regional assessment, sulfate levels measured from wet deposition at have decreased from levels measured in the early 1980s, as shown in Figure 4-1. There is a strong correlation between the decrease in $SO_2$ emissions in the mid-western states since 1970 and the decrease in average sulfate concentrations in the Northeast (Husain et al., 1998). This reflects emission reduction efforts pursuant to the terms of the Clean Air Act, enacted in 1970.

**Figure 4-1: Sulfate wet deposition, 1981-2003, at McFarland Hill NADP site**

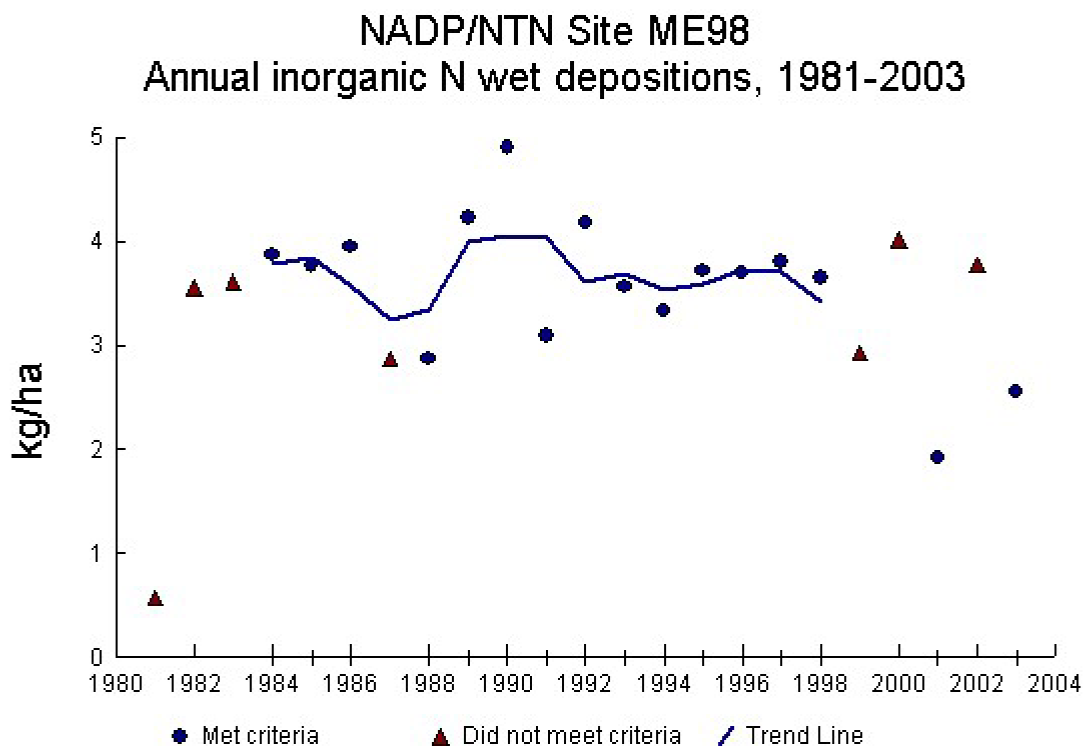



The level of inorganic nitrogen in wet deposition at McFarland Hill, depicted in Figure 4-2, also agrees with the regional data. There was not a substantial change in these levels throughout the 1980s or 1990s. Standards designed to reduce $NO_X$ emissions have likely been offset by increases of anthropogenic emissions from the burning of fossil fuels in the Mid-Atlantic States and the Ohio River Valley and reflecting agricultural sources from rural areas to the northwest of New Hampshire's seacoast (Lefer, 1997).

## Water Quality

Acadia NP contains at least 22 named lakes and ponds, more than 25 perennial and intermittent streams, and numerous wetlands located partially or entirely within its boundaries. These water bodies are exposed to impacts resulting from development within and adjacent to park lands, including sewage disposal, and non-point source pollution. Other impacts to ACAD water resources may come from oil or hazardous waste spills, landfill activity, high visitor use, and atmospheric deposition.

**Figure 4-2: Inorganic nitrogen wet deposition, 1981-2003, at McFarland Hill NADP site**




Davis et al. (1994) studied sediment cores from 12 acidic lakes in granitic, forested and uninhabited catchments in northern New England to reconstruct changes in pH and ANC. Trace metal chemistry data (lead, zinc, vanadium, and copper) suggested increased atmospheric deposition of metals started in New England in the early 1800s to 1900s. The cores indicated the 12 lakes were naturally acidic and had low ANC values in pre-industrial times. All of the lakes showed additional acidification since about 1920. Davis et al. concluded the recent acidification was due to atmospheric deposition.

Research and monitoring at ACAD since the mid -1980's has found that most park surface waters (lakes and streams), on average, are non-acidic. However, short-term episodic acidification of many lakes and streams does occur, especially during spring snowmelt and runoff. In addition, alkalinity values at ACAD are among the lowest in the region.

According to Kahl et al. (1992), the factors that contributed to episodic acidification included dilution from increased discharge, sulfuric acid input from precipitation or natural sources, nitric acid input from precipitation or natural processes in upper soil horizons, organic acid input from watershed soils or wetlands, and hydrochloric acid production from salt-effect reactions within watershed soils.

Heath et al. (1993) concluded that the most significant contributing factors to episodic acidification included input of natural acids from soil solutions, and input of sulfuric acid from precipitation. Less important mechanisms of episodic acidification included dilution by increased flow, increased $NO_3$ concentrations from precipitation or the large soil N pool, and increased export of organic acidity from soils. They interpreted many of the episodic acidification events as being due primarily to an ion-exchange salt effect of sodium ion for hydrogen ion in soil solution, and secondarily to dilution, neither of which is directly related to acidic deposition. They reported acid precipitation was a contributing, but non-essential, factor in these episodic acidifications.

Over the past 15 years, several studies have been conducted to document the effect of atmospheric and marine aerosol deposition on ACAD water bodies. Despite significant reductions in sulfur dioxide emissions and sulfate deposition during the past decade as a result of the Clean Air Act Amendments of 1990, the pH and acid neutralizing capacity of park waters remains relatively unchanged (Heath et al).

Kahl et al. (1993) collected lake chemistry data in Acadia NP from 1982 to 1989 and compared changes in lake chemistry to changes in deposition chemistry. They reported the NADP/NTN data showed non-significant declining concentrations of all solutes. During the same timeframe, 11 park lakes showed a slight increase in acid neutralizing capacity (ANC), a decrease in the sum of base cations, but no decrease in $SO_4$ concentrations.

Kahl (1999) reported on the status of Maine lakes after 1995 implementation of the $SO_2$ reductions mandated by the 1990 amendments to the Clean Air Act. He found $SO_4$ concentrations in sensitive Maine lakes had declined by 12 to 22 percent since 1982; however, there was not a concurrent decrease in lake acidity. Kahl reported a decline in base cation concentrations (e.g., Ca and Mg) as the reason for the lack of recovery. The base cation decline had been observed in sensitive watersheds over the entire northeastern U.S. According to Kahl, potential causes for the decline included continued high atmospheric deposition of N, a lag time in response, or the interrelated influence of climate and acidic deposition on watershed response.

## Aquatic Chemistry Data and DSS Results

### Horizon Report

The Horizon report was released for Acadia NP in August 1994. The report contains information on 16 water bodies in the parks. More water bodies exist, but were not sampled. More than half of the water bodies (56%) in the report contained data relevant to the DSS. The report details 10 lakes, 5 streams, and 1 ocean location in ACAD. Table 4-1 lists the number of sites that have data for each DSS component. With the exception of DOC, data are complete for streams, but are sparse for lakes.

**Table 4-1: Chemistry Component Summary - ACAD**

| | Total | Lakes | Streams | Ocean |
|---|---|---|---|---|
| Number | 16 | 10 | 5 | 1 |
| Conductance | 8 | 3 | 5 | 0 |
| pH | 9 | 4 | 5 | 0 |
| ANC | 9 | 4 | 5 | 0 |
| DOC | 3 | 3 | 0 | 0 |
| Nitrate | 8 | 3 | 5 | 0 |
| Base Cations | 8 | 3 | 5 | 0 |
| Sulfate | 8 | 3 | 5 | 0 |

None of the stream sites had no data elements used by the DSS, compared to 60% of lake sites. For those sites with data, the data is substantially complete. Three of four lake sites with DSS data and all of the stream sites with DSS data contained six or more of the data elements. As is typical at the parks studied, DOC data is fairly limited. With the exception of DOC data a standard set of chemical analyses were performed on water samples taken in ACAD.

**Table 4-2: Number of Elements Summary - ACAD**

| # of Elements | Total | Lakes | Streams | Ocean |
|---|---|---|---|---|
| 0 | 7 | 6 | 0 | 1 |
| 1 | 0 | 0 | 0 | 0 |
| 2 | 1 | 1 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 |
| 6 | 5 | 0 | 5 | 0 |
| 7 | 3 | 3 | 0 | 0 |

Of the 14 sites that had any data collection, including parameters not used by the DSS, 10 sites were last sampled in the 1970s and 4 in the 1980s. All of the data in this report are 15 years old or older and may not indicate current water chemistry conditions.

Of the 9 locations that had alkalinity data, sampling occurred only once at 33% of them. At these locations, the mean and extreme ANC values are the same. Alkalinity results were based on more than 10 samples at none of the locations.

## ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

### *Mean ANC*

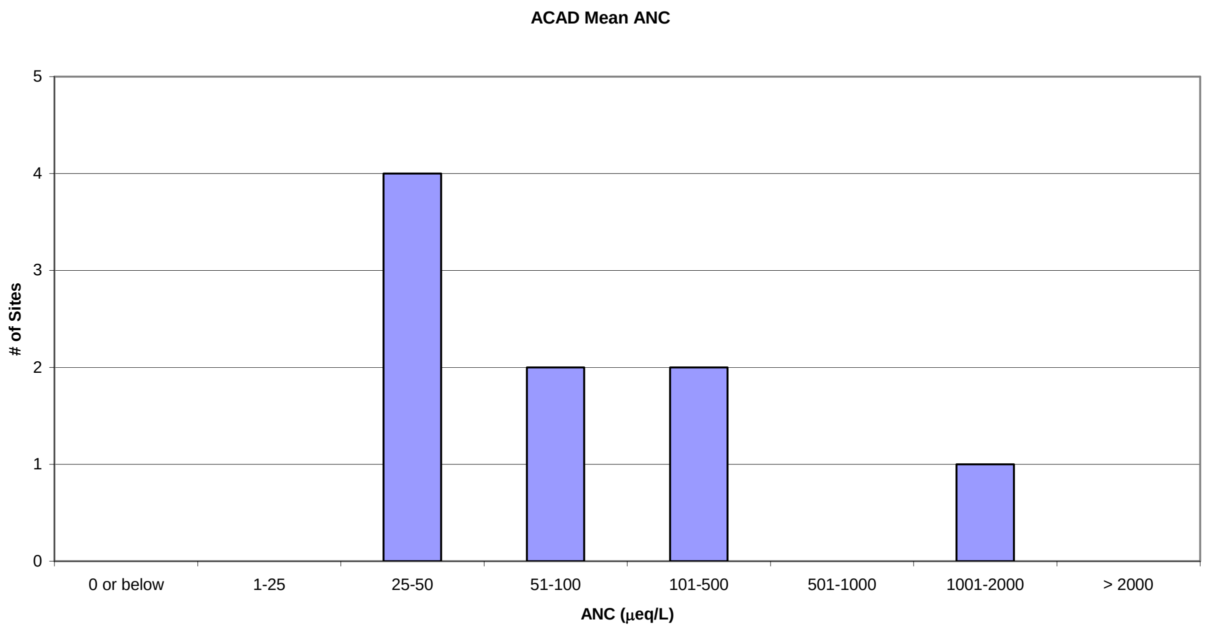
Of the 9 sampling locations which contained data for ANC calculations, 44% had a mean ANC below 50 μeq/L. These locations are listed below in Table 4-3.

**Table 4-3: Locations with mean ANC below 50 μeq/L - ACAD**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| ACAD0006 | Marshall Brook at Mountain Rd; Southwest Harbor, ME | 30.0 |
| ACAD0009 | Lower Hadlock Pond | 38.7 |
| ACAD0001 | Long Pond | 45.9 |
| ACAD0005 | Marshall Brook Tributary at Mountain Rd J; Southwest Harbor, ME | 50.0 |

Figure 4-3 contains a graph of the frequency distribution of mean ANC values in Acadia National Park.

**Figure 4-3: Frequency Distribution of Mean ANC Values - ACAD**




*Minimum ANC*

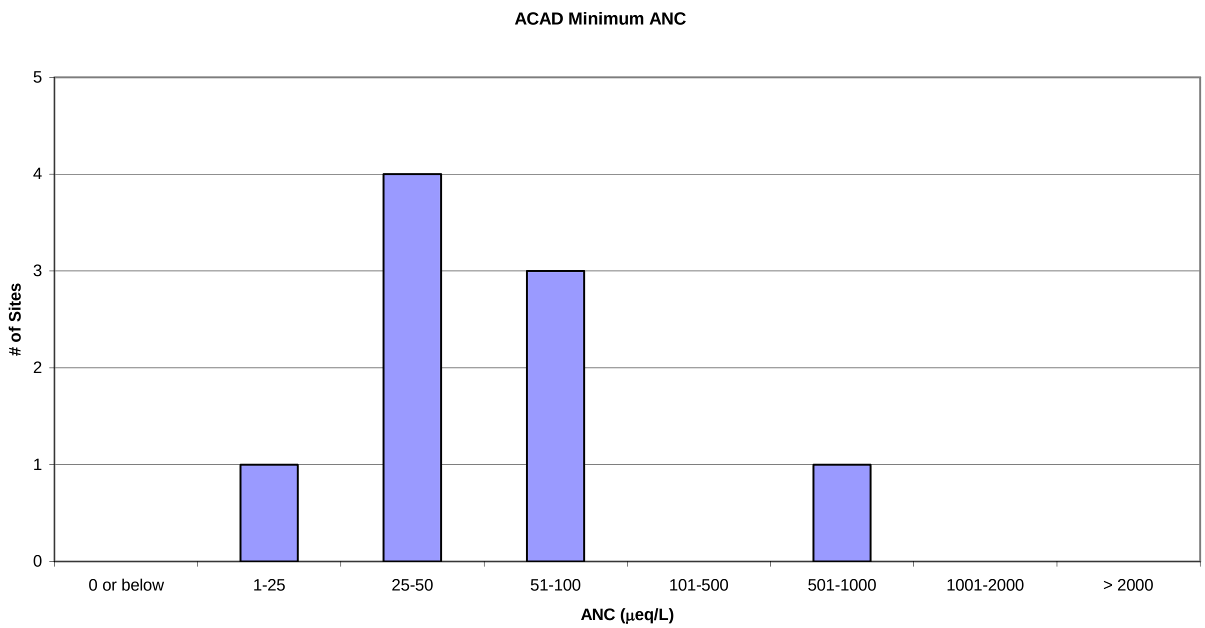
Of the 9 sampling locations which contained data for ANC calculations, 55% had minimum ANCs below 50 μeq/L. These locations are listed in Table 4-4.

**Table 4-4: Locations with minimum ANC below 50 μeq/L - ACAD**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| ACAD0006 | Marshall Brook at Mountain Rd; Southwest Harbor, ME | 20.0 |
| ACAD0009 | Lower Hadlock Pond | 38.7 |
| ACAD0002 | Marshall Brook below Seal Cove Rd; Southwest Harbor, ME | 40.0 |
| ACAD0005 | Marshall Brook Tributary at Mountain Rd J; Southwest Harbor, ME | 40.0 |
| ACAD0001 | Long Pond | 45.9 |

Figure 4-4 contains a graph of the frequency distribution of minimum ANC values in Acadia National Park.

**Figure 4-4: Frequency Distribution of Minimum ANC Values - ACAD**




## Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

### *Lakes - Average Water Chemistry Values*

Table 4-5 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in Acadia National Park and Figure 4-5 includes graphical representations of this data.

**Table 4-5: DSS Results for Average Lake Values - ACAD**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Acid Deposition Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid Deposition | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 0 | 0 | 0 | 0 | 3 | 3 | 0 |
| -0.59 to -0.20 | 0 | 0 | 4 | 0 | 1 | 0 | 3 |
| -0.19 to 0.20 | 4 | 4 | 0 | 4 | 0 | 1 | 0 |
| 0.21 to 0.60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

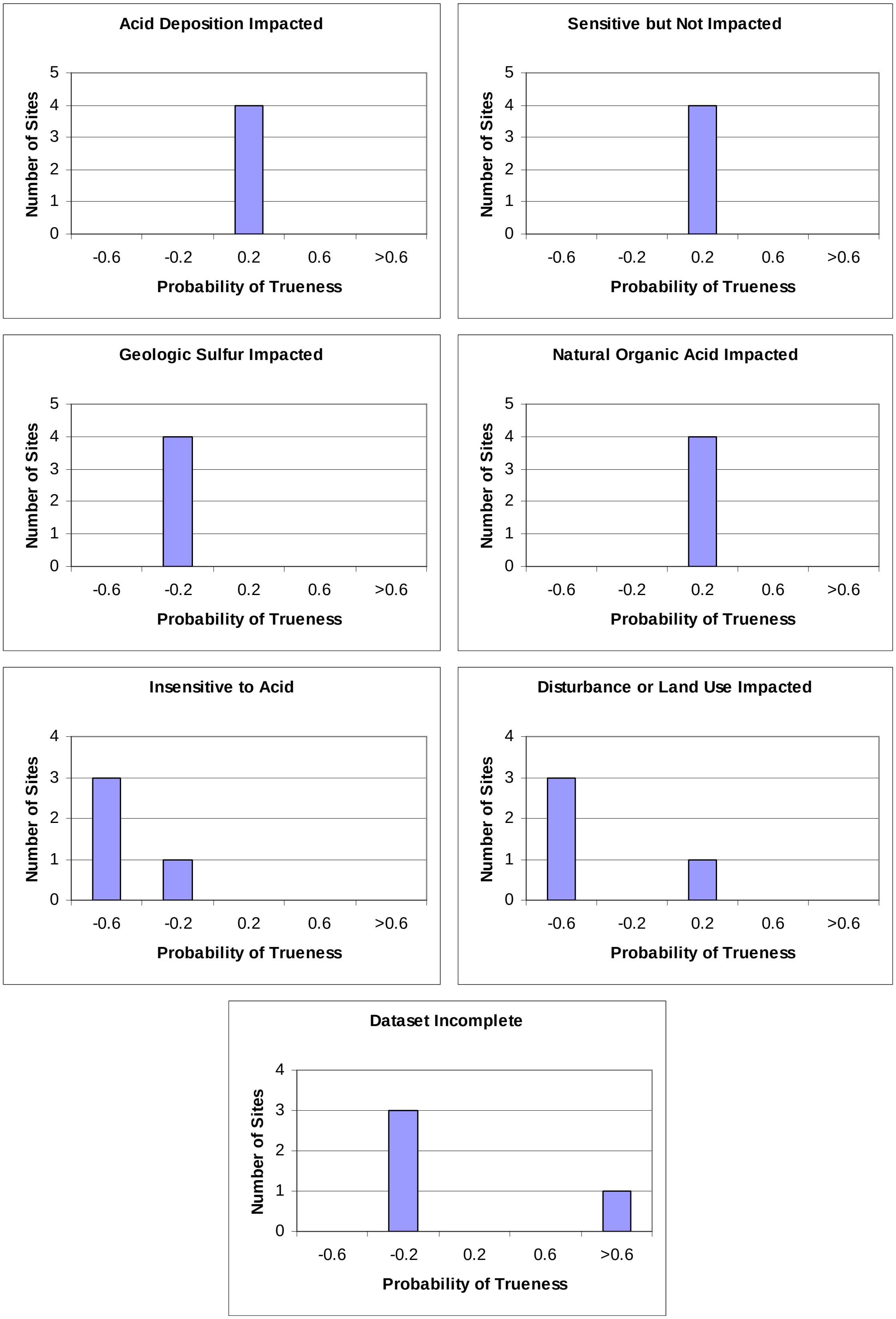
The DSS made no assessment (categories were neither true nor false) on lakes being impacted by atmospheric deposition ('Acid Deposition Impacted' category) or by high levels of organic material ('Natural Organic Acid Impacted' category). It also did not make an assessment on whether lakes were sensitive to future acid deposition, but not yet impacted ('Sensitive but not Impacted' category). Atmospheric deposition is influenced by nitrate and sulfate concentrations; nitrate levels were low (<1 μeq/L) while sulfate levels were high (>280 μeq/L). However, chloride levels were also high (≥169 μeq/L); high chloride levels at coastal locations indicate that much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid. The DSS could not make recommendations based on the levels of nitrate and sulfate provided. Organic impacts are influenced mainly by DOC levels; at medium levels (2-3 mg/L) in this region, the DSS could not make a recommendation in this category.

The DSS found all of the lakes to not be impacted by high levels of geologic sulfur (false in the 'Geologically Sulfur Impacted' category). As stated above, much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid. High sulfate levels are expected at coastal locations (Sullivan et al., in review).

All four lakes were considered sensitive to acid input (false in the 'Insensitive to Acid' category). This results from low ANC values; 3 of the four lakes had ANCs < 55 μeq/L). These lakes are Long Pond (ACAD0001), Lower Hadlock Pond (ACAD0009), Echo Lake (Mount Desert) (ACAD0010), and Upper Hadlock Pond (ACAD0012). Given this result and since no assessment was made concerning the lakes being sensitive to acid inputs but not yet impacted, the DSS is unsure about whether or not the lakes are impacted, but concludes if they probably are sensitive.

The three lakes with nitrate data were categorized by the DSS as not being effected by extremely high levels of nitrate caused by land use or disturbances (false in the 'Land Use/Disturbance' category). The nitrate levels for all 3 lakes were very low (<1 μeq/L).

**Figure 4-5: Charts of DSS Results for Average Lake Values - ACAD**



The DSS evaluates all of the locations in terms of the completeness of the input data. All of the locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data.

*Lakes – Extreme Water Chemistry Values*

Table 4-6 lists the results of the DSS for extreme values of water chemistry parameters in lakes in Acadia NP. Figure 4-6 graphically represents these results.

**Table 4-6: DSS Results for Extreme Lake Values - ACAD**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 0 | 0 | 0 | 0 | 3 | 3 | 0 |
| -0.59 to -0.20 | 0 | 0 | 4 | 0 | 1 | 0 | 3 |
| -0.19 to 0.20 | 4 | 4 | 0 | 4 | 0 | 1 | 0 |
| 0.21 to 0.60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

The DSS result distribution for extreme lake values are exactly the same as that for average lake values. This occurred for two reasons. First, results at 75% of the lake locations came from a single test at that location. Therefore, the mean value for a parameter and its minimum value are the same. Second, the remaining lake was sampled on only three occasions; the mean and extreme values for this lake were quite similar.

*Streams - Average Water Chemistry Values*

Table 4-7 lists the results of the Synthesis DSS for average water chemistry values at streams in Acadia NP and Figure 4-7 represents this data graphically.

**Table 4-7: DSS Results for Average Stream Values - ACAD**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 0 | 0 | 1 | 0 | 3 | 3 | 0 |
| -0.59 to -0.20 | 0 | 0 | 4 | 0 | 0 | 0 | 0 |
| -0.19 to 0.20 | 5 | 5 | 0 | 5 | 0 | 0 | 5 |
| 0.21 to 0.60 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |

**Figure 4-6: Charts of DSS Results for Extreme Lake Values - ACAD**

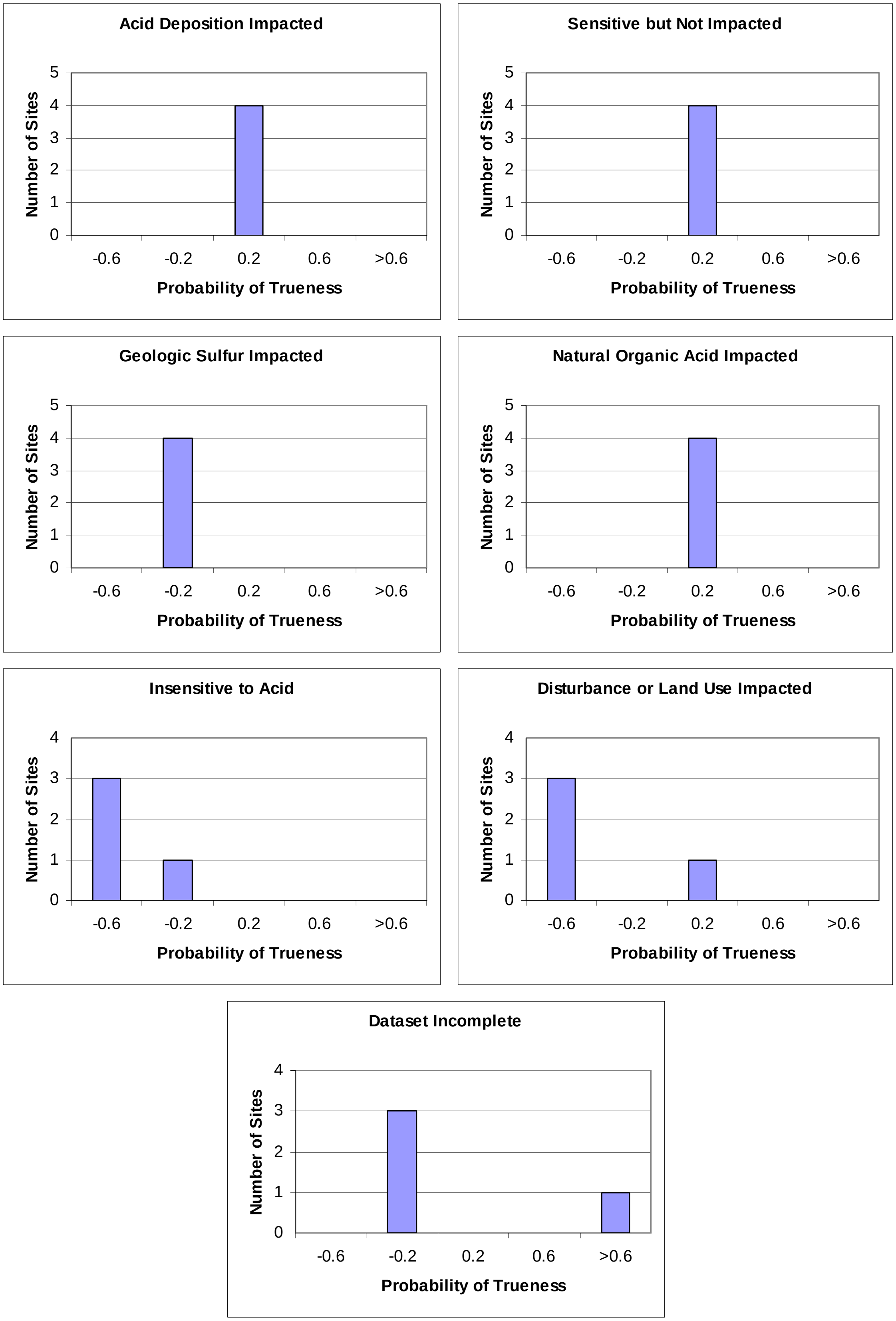
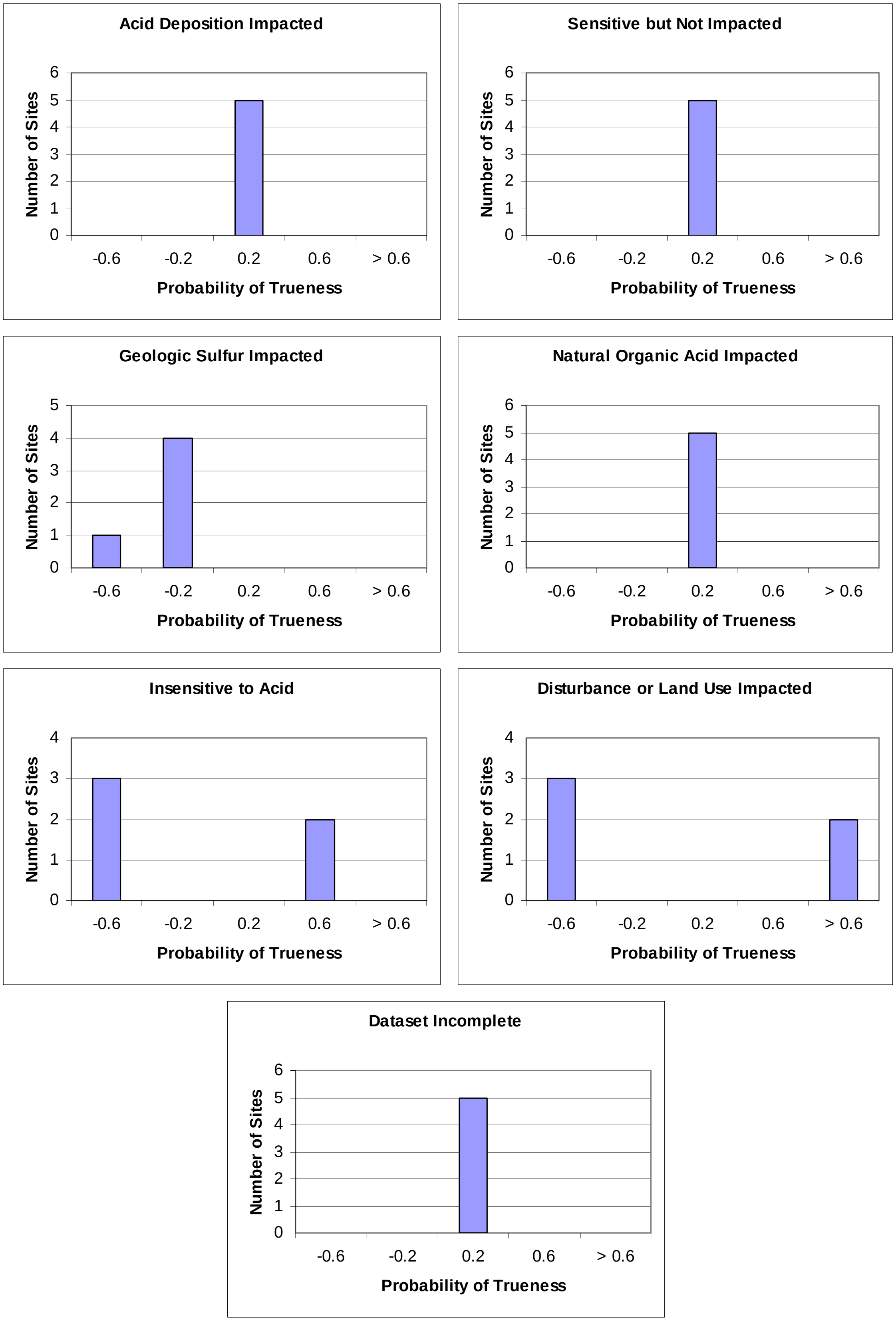


**Figure 4-7: Charts of DSS Results for Average Stream Values - ACAD**



The DSS made no assessment (categories were neither true nor false) on streams being impacted by atmospheric deposition (‘Acid Deposition Impacted’ category) or by high levels of organic material (‘Natural Organic Acid Impacted’ category). It also did not make an assessment on whether streams were sensitive to future acid deposition, but not yet impacted (‘Sensitive but not Impacted’ category). Nitrate levels for 3 of the streams were low (≤5 μeq/L) and the DSS concludes there is no disturbance or land use impact on these streams. Nitrate levels are high for the other 2 streams (>50 μeq/L), too high to be solely from anthropogenic deposition but likely a result of possible disturbance or land use impact. Sulfate levels were moderate, between 125 μeq/L and 156 μeq/L. Chloride levels were high (≥169 μeq/L); high chloride levels at coastal locations indicate that much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid. The DSS could not make recommendations regarding possible acid deposition impact based on the levels of nitrate and sulfate provided. Organic impacts are influenced mainly by DOC levels; since there was no DOC data for any of the streams, the DSS could not make a recommendation in this category.

The DSS found all of the streams to not be impacted by high levels of geologic sulfur (false in the ‘Geologically Sulfur Impaired’ category). As stated above, much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid. In addition, high sulfate levels are expected at coastal locations (Sullivan, in review).

Three of the five streams sampled were considered sensitive to acid input (false in the ‘Insensitive to Acid’ category). This results from low ANC values; these streams had ANCs ≤60 μeq/L). These streams are the Marshall Brook Tributary at Seal Cove Road (ACAD0003), the Marshall Brook Tributary at Mountain Road J (ACAD0005), and Marshall Brook at Mountain Road (ACAD0006). Given this result and since no assessment was made concerning the streams being sensitive to acid inputs but not yet impacted, the DSS is unsure about whether or not the streams are impacted, but not if they are sensitive. The other two streams were considered probably not sensitive to acidic inputs due to high buffering capacity (true in the ‘Insensitive to Acid’ category). This is reflected in their high mean ANC values (>150 μeq/L).

These same three streams that were considered sensitive to acidic inputs, the Marshall Brook Tributary at Seal Cove Road (ACAD0003), the Marshall Brook Tributary at Mountain Road J (ACAD0005), and Marshall Brook at Mountain Road (ACAD0006), are considered by the DSS as not being affected by extremely high levels of nitrate caused by land use or disturbances (false in the ‘Land Use/Disturbance’ category). The nitrate levels for all 3 streams were low (≤5 μeq/L). The DSS is unsure if these streams are not impacted or impacted by acid deposition or high organic content.

The two streams considered insensitive to acid, Marshall Brook below Seal Cove Road (ACAD0002) and Marshall Brook at Seal Cove Road (ACAD0004), were found to be impacted by land use or disturbance (true in the ‘Land Use/Disturbance’ category). This is due to nitrate levels (>50 μeq/L) too high to be solely from anthropogenic deposition.

While it may seem counterintuitive that a water body can be both impacted (in this case by land use or disturbance) and insensitive to acid, this outcome is reasonable. These results demonstrate that the model allows for some uncertainty in definitely adding a stream into one category at the exclusion of all others. These streams are unlikely to be affected by relatively low concentrations of sulfate and the acid associated with acid deposition due to their high buffering capacity; however, they probably have been impacted by high levels of nitrogen from disturbance or land use. The impact to these streams would be worse if they were not so well buffered.

The DSS evaluates all of the locations in terms of the completeness of the input data. All of the stream locations had less than complete datasets (no DOC data). This prevents the DSS from concluding if there is impact from natural organic acid.

*Streams - Extreme Water Chemistry Values*

Table 4-8 contains the results of the Synthesis DSS of extreme water chemistry value for streams in Acadia National Park. Figure 4-8 includes graphs of the data in this table.

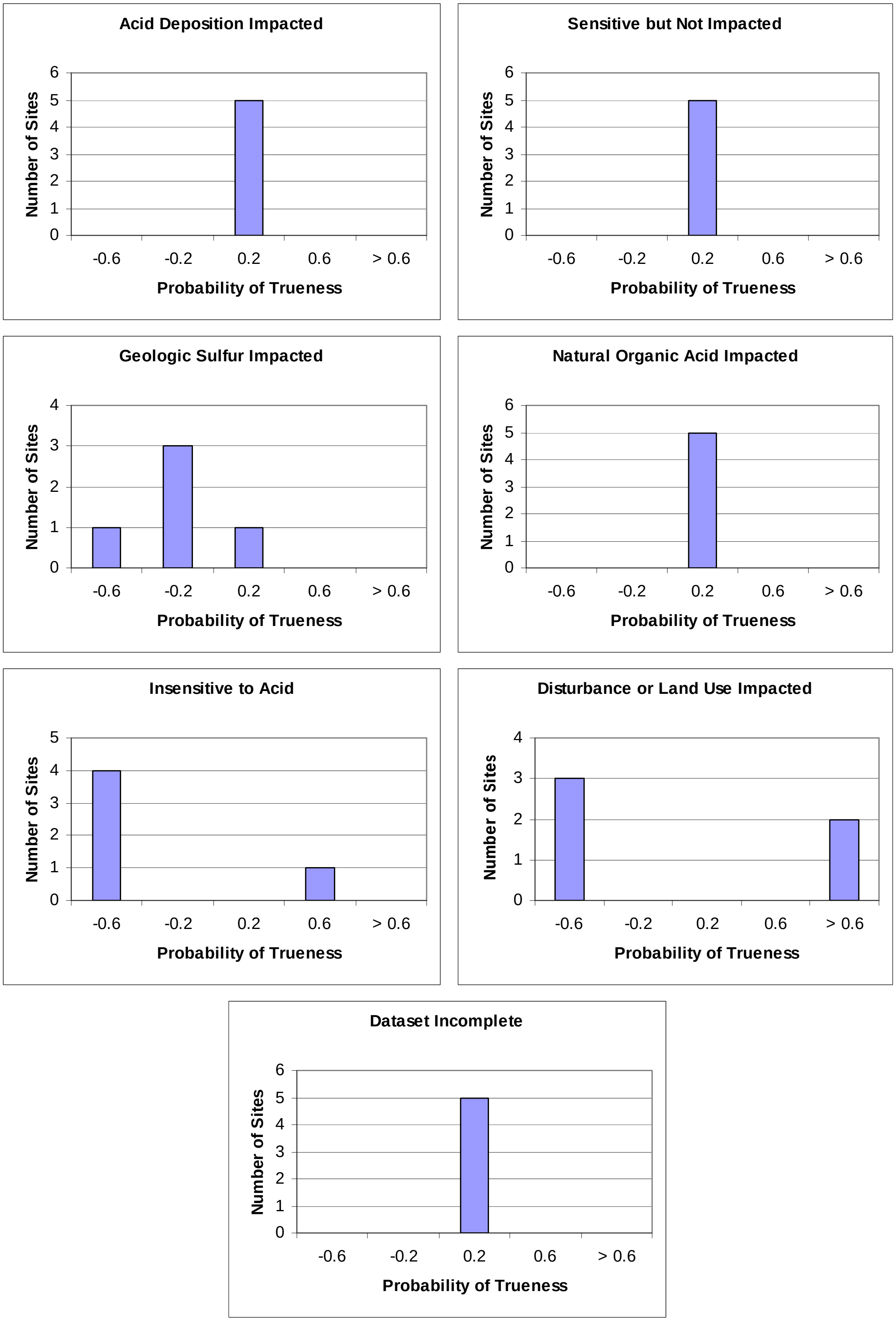
**Table 4-8: DSS Results for Extreme Stream Values - ACAD**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 0 | 0 | 1 | 0 | 4 | 3 | 0 |
| -0.59 to -0.20 | 0 | 0 | 3 | 0 | 0 | 0 | 0 |
| -0.19 to 0.20 | 5 | 5 | 1 | 5 | 0 | 0 | 5 |
| 0.21 to 0.60 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |

All of the stream data was based on two samples at each location; many of the mean and extreme values are quite similar. As it did with the average stream data, the DSS made no assessment (categories were neither true nor false) on streams being impacted by atmospheric deposition (‘Acid Deposition Impacted’ category), high levels of organic material (‘Natural Organic Acid Impacted’ category), and on whether streams were sensitive to future acid deposition, but not yet impacted (‘Sensitive but not Impacted’ category). Again, this is mainly due the uncertainty found in the nitrate and sulfate levels and the lack of DOC data.

The DSS found four of the streams probably not to be impacted by high levels of geologic sulfur (false in the ‘Geologically Sulfur Impaired’ category). Sulfate levels were moderate, between 125 $\mu$eq/L and 167 $\mu$eq/L. Chloride levels were high (>160 $\mu$eq/L), indicating that much of the sulfate may have come from neutral sea spray as opposed to sulfuric acid.

**Figure 4-8: Charts of DSS Results for Extreme Stream Values - ACAD**



Four streams were considered sensitive to acid input (false in the 'Insensitive to Acid' category). This results from low ANC values; the streams had minimum ANCs <60 μeq/L. These streams are Marshall Brook below Seal Cove Road (ACAD0002),the Marshall Brook Tributary at Seal Cove Road (ACAD0003), the Marshall Brook Tributary at Mountain Road J (ACAD0005), and Marshall Brook at Mountain Road (ACAD0006). Marshall Brook at Seal Cove Road (ACAD0004) had a minimum ANC value of 720 μeq/L, indicating it has high buffering capacity. This stream should not be adversely impacted by future acidic inputs (true in the 'Insensitive to Acid' category).

Three streams, the Marshall Brook Tributary at Seal Cove Road (ACAD0003), the Marshall Brook Tributary at Mountain Road J (ACAD0005), and Marshall Brook at Mountain Road (ACAD0006), are considered as by the DSS as not being effected by extremely high levels of nitrate caused by land use or disturbances (false in the 'Land Use/Disturbance' category). The nitrate levels for all 3 streams were low (≤8 μeq/L). The DSS is unsure if these streams are not impacted or impacted by acid deposition or high organic content.

Two streams, Marshall Brook below Seal Cove Road (ACAD0002) and Marshall Brook at Seal Cove Road (ACAD0004), were found to be impacted by land use or disturbance (true in the 'Land Use/Disturbance' category). This is due to nitrate levels (>70 μeq/L) too high to be solely from anthropogenic deposition.

Marshall Brook at Seal Cove Road (ACAD0004) was found to be both impacted (in this case by land use or disturbance) and insensitive to acid. These results demonstrate that the model allows a site into more than one category.

The DSS evaluates all of the locations in terms of the completeness of the input data. All of the locations had less than complete datasets and are missing DOC data.

## Analysis

In agreement with the Acadia NP Water Resources Fact Sheet, the data from the Horizon report shows alkalinity values at ACAD are low. Five of the 9 lake or stream locations tested had minimum ANC values below 50 μeq/L; two locations had minimum ANC values between 50 and 60 μeq/L. Waters with low buffering capacity are more susceptible to both episodic and chronic acidification.

The Fact Sheet also states that most park surface waters, on average, are non-acidic. The DSS results do not give support for or evidence against this statement. Consistent with the low alkalinity of these waters, the DSS found 8 of the 9 waters to be sensitive to future acidic episodes. The DSS comments that nitrate levels, with 2 exceptions, are not high enough to indicate that the waters have been impacted by land use or disturbance. Sulfate levels are too low, give the proximity of the park to the ocean, to indicate acidification from geologic sulfur. The DSS cannot determine whether these waters are already impacted by acid deposition.

Whether these results are representative for the entire park is questionable as only 18% of lakes and 20% of streams had data in the Horizon report. Also, with the exception of a single lake, the data in the report are based on one or two samples at each location; this data may not indicative of the true chemistry of the water body. It is possible that some of the more sensitive waters in ACAD were not captured in the Horizon report.

Nitrate and sulfate in these lakes and streams may not indicate the effects of air pollution. The average level of nitrate across these waters is very low. 75% of locations that have nitrate data are at levels below 8 μeq/L. Although absolute sulfate levels are high, much of the sulfate probably comes from neutral sea salts from the nearby ocean and not from atmospheric deposition or geologic sources. Figure 4-1 shows that sulfate in wet deposition has declined throughout the last decade. Further evidence is that none of the measured pH levels, in both the average and extreme cases, measured below 6.

Dissolved organic carbon levels are available only for three lakes and for no streams. DOC values range from 2.4 to 3.1 mg/L. The DSS results are uncertain regarding organic acid effects.

A body of water that has an ANC of below 50 μeq/L is at risk to impact from exposure to acid. The 5 water bodies that had ANC values that met this criterion are listed in Table 4-9.

**Table 4-9: ACAD Water Bodies with Minimum ANC <50 μeq/L**

| Location ID | Location Name | Sample Type | Impact(s)* | # Obs | Last Sampled** |
|---|---|---|---|---|---|
| ACAD0001 | Long Pond | Lake | Sensitive to Acid | 1 | 1984 |
| ACAD0002 | Marshall Brook below Seal Cove Road | Stream | Sensitive to Acid; Disturbance/Land Use | 2 | 1979 |
| ACAD0005 | Marshall Brook Tributary at Mountain Road J | Stream | Sensitive to Acid | 2 | 1979 |
| ACAD0006 | Marshall Brook at Mountain Road | Stream | Sensitive to Acid | 2 | 1979 |
| ACAD0009 | Lower Hadlock Pond | Lake | Sensitive to Acid | 1 | 1984 |

For the Acid Impacted and Sensitive/Unimpaired categories, the DSS returned a ‘true’ value for these locations; for the Insensitive to Acid category, the DSS returned a ‘false’ value.

**”Last sampled” refers to last documented sample in the Horizon Report used in this report.

In addition to the five locations listed in Table 4-9, using extreme water chemistry values, the DSS suggested that one lake and one stream are sensitive to future acid deposition, while one stream location was already impacted by geologic sulfur. Table 4-10 lists all sites the DSS flagged as currently or potentially impacted by acid at ACAD, using the extreme water chemistry values. A discussion of these locations will follow.

**Table 4-10: Currently and Potentially Sensitive ACAD Waters Based on Extreme Water Chemistry Values**

| Location ID | Location Name | Impact(s)* | # Obs | Last Sample |
|---|---|---|---|---|
| ACAD0001 | Long Pond | Sensitive to Acid | 1 | 1984 |
| ACAD0002 | Marshall Brook below Seal Cove Rd | Sensitive to Acid<br>Disturbance/Land Use | 2 | 1979 |
| ACAD0003 | Marshall Brook Tributary at Seal Cove Rd | Sensitive to Acid | 2 | 1979 |
| ACAD0004 | Marshall Brook at Seal Cove Rd | Disturbance/Land Use | 2 | 1979 |
| ACAD0005 | Marshall Brook Tributary at Mountain Rd J | Sensitive to Acid | 2 | 1979 |
| ACAD0006 | Marshall Brook at Mountain Rd | Sensitive to Acid | 2 | 1979 |
| ACAD0009 | Lower Hadlock Pond | Sensitive to Acid | 1 | 1984 |
| ACAD0010 | Echo Lake Mount Desert | Sensitive to Acid | 3 | 1984 |

* For the Disturbance/Land Use Impacted category, the DSS returned a 'true' value for these locations; for the Insensitive to Acid category, the DSS returned a 'false' value.

One of the main findings identified in research performed in ACAD and in New England is that waters in this area tend to have low buffering capacities. This is consistent with the data used in the DSS. The DSS suggested that 7 of the 9 sampled waters are sensitive to future acid deposition. This includes the five locations where the minimum ANC value was less than 50 μeq/L; the two other locations are ACAD0003, Marshall Brook Tributary at Seal Cove Rd (minimum ANC = 60 μeq/L), and ACAD0010, Echo Lake Mount Desert (minimum ANC = 100 μeq/L). With the exception of Echo Lake Mount Desert, the classification was based on the low minimum ANC value.

Another research result shows that despite being subject to acid rain, waters tend not to be acidic. The DSS suggested that only 2 of the 9 locations with data were acid impacted, both by disturbance or land use. At both of these locations, nitrate levels were at much higher levels than could be reasonably accounted for by atmospheric deposition. At ACAD0002 (Marshall Brook below Seal Cove Rd), the maximum nitrate level was 70 μeq/L; at ACAD0004 (Marshall Brook at Seal Cove Rd), it was 107 μeq/L. Since the data at each location are based on only 2 samples, it is not possible to say whether the nitrate levels are episodic or chronic in nature.

While the DSS does not suggest that waters in ACAD are generally acidic, it does not the show the opposite to be true either. In fact, at all locations, the DSS was unable to make a recommendation with any certainty in the 'Acid Deposition Impacted, 'Sensitive but Unimpacted', and 'Organic Acid Impacted' categories. In the 'Organic Acid Impacted' category, this is due to the lack of DOC data collected. For the other categories, there are data but the DSS is unable to provide a classification with significant certainty.

At first glance, the sulfate concentrations at all ACAD locations appear to be high (≥ 125 μeq/L). However, as shown in Figure 2-1, the sulfate levels for the 'Geologic Sulfur Acid Impacted' category are much higher for the Northeastern Region than they are for the other regions. Much of this sulfate comes from neutral sea salts from the ocean as opposed to primarily acidic atmospheric or geologic sources.

## Conclusion

Sulfate and nitrate are the most important anionic components in acidic deposition. The deposition of sulfate in precipitation in northern New England measured at four locations, including Acadia National Park, has decreased approximately 30% since the early 1980s, mainly in response to meeting the standards specified in the Clean Air Act. Nitrate deposition concentrations do not show a pattern over the same time period.

This evaluation focuses on Acadia NP (ACAD). The water quality data were extracted from the Horizon report, completed in August 1994. Values for specific conductance, pH, ANC, DOC, nitrate, the sum of base cations, and sulfate were obtained. These reports may not contain data for the most sensitive water bodies; for example, the report contains data only 9.1% of lakes and 20% of streams in ACAD. Therefore, the analysis may not give a true representation of the sensitivity or level of impact by acid deposition for the entire park.

Waters in the Atlantic Northeast are under great scrutiny for two reasons. First, they have historically low buffering capacity. Second, despite the decline in sulfur deposition, this region has been greatly affected by acid rain. A regional report for New England found that acidification in waters has not decreased despite decreases in sulfate concentrations. However, the Aquatic Chemistry DSS, using the Horizon data, found only 2 of the 9 water bodies to be currently acid impacted, both due to high nitrate concentration as a consequence of agricultural activities, forestry, or other land use. At both locations, nitrate concentrations were extremely high (≥ 70 μeq/L). These concentrations are higher than any that can reasonably be explained by atmospheric deposition. Due to a limited number of sample observations, it cannot be determined if the acidification is episodic or chronic in nature.

A body of water that has an ANC of below 50 μeq/L is at risk to impact from exposure to acid. Five of the 9 water bodies that had ANC values met this criterion: Long Pond, Marshall Brook below Seal Cove Road, Marshall Brook Tributary at Mountain Road J, Marshall Brook at Mountain Road, and Lower Hadlock Pond. Two other waters suggest sensitivity to future acid deposition based on extreme stream values: Marshall Brook Tributary at Seal Cove Rd (minimum ANC of 60 μeq/L), and Echo Lake Mount Desert. The DSS could not make a recommendation with any certainty concerning acidification due to acid deposition or organic sources, the latter because there were no data for DOC.

Data issues that affected this analysis include a general lack of data, infrequent sampling, and old data. At most, the results contain data from three samples. All of the stream locations were sampled twice; with the exception of the lake that was sampled three times, the rest of the lakes in ACAD were sampled once. In these cases, the result is 'extreme' values that are the same as the mean values. In general, extreme water chemistry values were very similar to average values. With so few samples, it is difficult to ascertain if the data assembled are representative of the water body in question. Only 56% of water bodies in the report contained data relevant to the DSS. Of the 9 sites with data, 89% of them had six or seven data elements available for use by the DSS. Data representing present conditions are needed. The lakes were last sampled in 1984; the streams in 1979. The Horizon report is 10 years old. It is likely the condition of these waters has changed during this period.

The DSS does not show evidence of high levels of acidification in the waters within Acadia National Park. The DSS has identified two areas of Marshall Brook that may require attention. These two locations, at and below Seal Cove Road, are primary spots where further sampling is recommended. The six other locations that the DSS flagged as sensitive to acid, four of which have ANC values of less than 50 $\mu$eq/L and one less than 60 $\mu$eq/L, should be monitored for changes.

# Chapter 5 - Air and Water Quality in the Pacific Northwest Region

The information in this section was taken from the Status of Air Quality and Effects of Atmospheric Pollutants on Ecosystems in the Pacific Northwest Region of the National Park Service (Eilers et al. 1994). The complete report is available on the Internet at the following site:

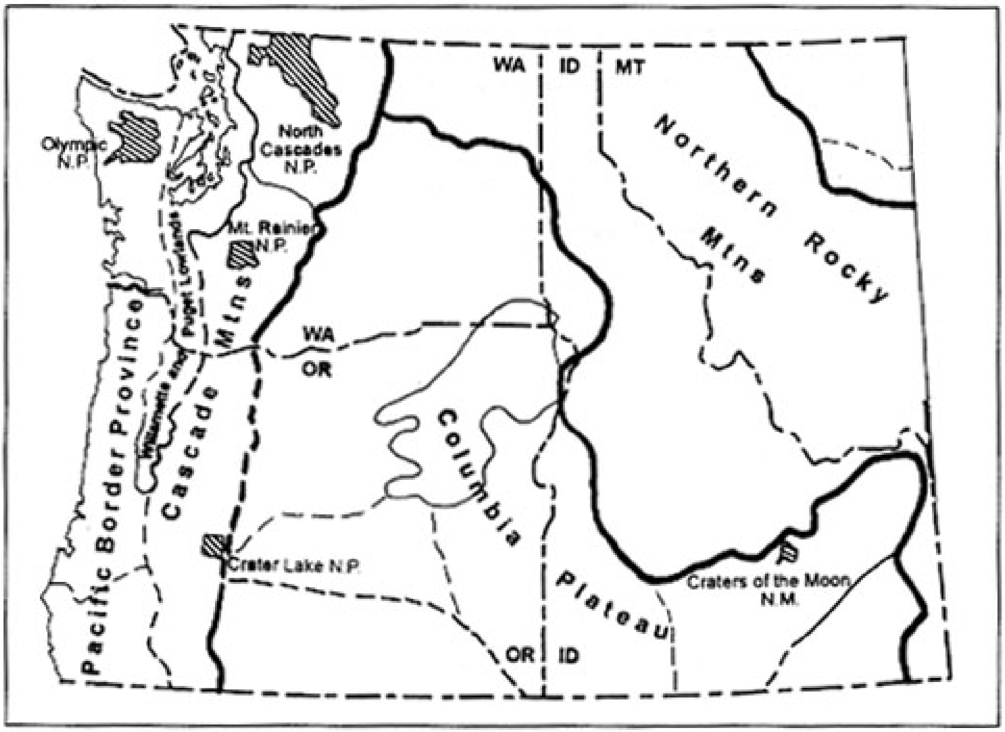
http://www2.nature.nps.gov/air/pubs/PacificNW.Review/index.html

This section is not meant to be a complete discussion of air and water quality in the Pacific Northwest Region nor a complete bibliography. Instead it provides an introduction to some of the environmental factors that are thought to most influence the lakes and streams described in this chapter. Some of the sources of emissions discussed here have changed greatly during the time that the data on the region's lakes and streams were collected and likely will continue to change as a result of emissions controls. Similarly, additional monitoring and research continue in the region and improve our ability to understand the changes in the chemistry of lakes and streams.

## Environmental Setting

The Pacific Northwest is a diverse region comprised of a coastal zone, the Cascade Range, and the Columbia Plateau provinces. Figure 5-1 follows the regionalization scheme of Fenneman (1946), based on broad patterns in precipitation, vegetation, soils, and geology. These patterns reflect the major distinction in the region between the wet, mountainous areas in the west and the more arid climate to the east.

**Figure 5-1: Physiographic provinces of the Pacific Northwest (Fenneman 1946) and location of class I national parks and monuments.**




## Air Quality

The air quality in the Pacific Northwest region is very good compared to other areas of the U.S. Accumulated air pollutant loads are low because principal air masses derive from the atmosphere over the Pacific Ocean. Also, emissions of principal air pollutants within the Pacific Northwest are low relative to other regions. Thus, precipitation quality in the region generally is high. However, non-marine sulfate and hydrogen ion concentrations in precipitation for portions of the Washington Cascades, including Mount Rainier National Park (MORA) and North Cascades National Park (NOCA), are slightly elevated compared to concentrations in precipitation measured on the west side of Olympic National Park (OLYM).

## Lake and Stream Chemistry

### Overview

At the time of this report, complete water chemistry data existed for relatively few lakes and streams in the parks. The available data generally lack analysis of key variables or are inadequate for these dilute waters (e.g., single-end-point alkalinity given instead of Gran acid neutralizing capacity; Gran acid neutralizing capacity is now considered more appropriate for such dilute waters). Sampled surface waters were not selected in a fashion statistically representative of waters within the parks.

As a result, the relative sensitivity of lakes and streams in the parks to acidic deposition can only be estimated based on available data for a few documented highly sensitive lakes.

Based on assessments of current surface water chemistry, lakes in this region are likely among the most sensitive aquatic systems anywhere in the world (Eilers et al. 1990, 1991). Sampling of high-elevation lakes by Brakke (1984, 1985), Landers et al. (1987), and Liss et al. (1991) shows that low-ANC (~ 10 μeq/L) lakes are present and presumably sensitive to acidic deposition. It is clear that potentially highly-sensitive lakes and streams are found in North Cascades and Mount Rainier NPs. The lowest measured ANC was for Lake Ann, located just outside the park boundaries of North Cascades. With ANC of 3.5 μeq/L, a pH of 5.4, and conductivity of 2.8 μS/cm, this lake clearly represents the extreme of watershed sensitivity (Brakke 1984).

## Sulfate

Sulfate is the most important anion, on a quantitative basis, in acidic deposition in most parts of the United States. The responses of watersheds to S inputs, particularly chronic effects on surface water quality, are now reasonably well understood.

Relatively minor increases in lakewater $SO_4^{2-}$ concentration could lead to chronic acidity (ANC less than 0) in many lakes in the Cascade Range because of their low ANC.

## Nitrate

The second important acid anion found in acidic deposition is nitrate. Nitrate and ammonium, which can be converted to nitrate within the watershed, have the potential to acidify drainage waters and leach potentially toxic aluminum (Al) from watershed soils. An important form of N deposition to these forests may be fog, especially in higher elevation sites of MORA and NOCA (Eilers et al. 1994).

In many watersheds, N is the limiting nutrient for plant growth, and therefore most N inputs are quickly incorporated into biomass as organic N with little leaching of nitrate into surface waters. However, under certain circumstances, atmospherically-deposited N can exceed the capacity of forest ecosystems to take it up. This N saturation can lead to base cation depletion, soil acidification, and leaching of $NO_3^-$ from soils to surface waters.

Nitrate in snowmelt runoff is an important component of biological damage resulting from atmospheric deposition (cf. Wigington et al. 1990). Nitrate is the principal acid anion in snowmelt in many areas of the northeastern and western United States. Selective separation of $NO_3^-$ from the snowpack can result in early spring runoff having concentrations substantially greater than the average snowpack concentrations.

Nitrate concentrations in surface waters exhibit a strong seasonality; $NO_3^-$ is typically elevated during late winter and spring, particularly during periods of snowmelt, and reduced to low or non-detectable levels throughout summer and fall. This can be attributed to seasonal growth patterns of forest vegetation. Vegetation growth is reduced or stopped entirely during winter months, and microbial assimilation of N is also reduced during this season. Spring snowmelt can act to flush into lakes and streams N that was deposited in the snowpack from atmospheric deposition or N mineralized within the soil during winter.

## Episodic Effects

Acidic deposition may cause episodic acidification of surface waters at even lower levels of increased deposition. There is limited data availability concerning stream and lake chemistry during snowmelt and precipitation events, seasonal surface water chemistry data, watershed dynamics, and deposition data, particularly at high-elevation sites. Both S and N may be important agents of episodic and seasonal acidification. Acidic deposition contributes to episodic acidification particularly via enhanced $NO_3^-$ leaching. Under some conditions, episodes can also be partially caused by increased $SO_4^{2-}$ concentration. There is also the possibility that chronic acidification by acid deposition can pre-condition a watershed, thereby increasing the severity of episodic acidification.

Lakes and streams that have been studied throughout the United States, Canada, and Europe nearly all experience loss of ANC during hydrologic events (Wigington et al. 1990). Periods of episodic acidification may last for hours to weeks, and sometimes result in depletion of ANC to negative values with concurrent increases in potentially-toxic inorganic Al in solution. Chemical changes during episodes are controlled by a number of natural processes, including dilution of base cation concentrations, nitrification, flushing of organic acids from terrestrial to aquatic systems, and the neutral salt effect.

The effects of N deposition on surface waters are expected to be primarily episodic in nature. Unfortunately, data required to make regional assessments of episodic effects are generally not available. Sampling during snowmelt can be particularly difficult in the high mountains of the West, when study sites are often inaccessible, and when motorized transport (e.g., via snowmobile) is often not allowed due to wilderness restrictions.

# Chapter 6 - Mount Rainier National Park

## Background

The information in this section was taken from the Status of Air Quality and Effects of Atmospheric Pollutants on Ecosystems in the Pacific Northwest Region of the National Park Service (Eilers et al. 1994). The complete report is available on the Internet at the following site:

http://www2.nature.nps.gov/air/pubs/PacificNW.Review/index.html

## Description

Mount Rainier National Park was established as the nation's fifth national park in 1899. At 4392 m, Mount Rainier is the fifth tallest peak in the contiguous 48 states. The mountain occupies more than one-fourth of the park's 98,000 ha area. Sixty miles southeast of Seattle, Washington, Mount Rainier is the highest in the chain of volcanoes comprising the Cascade Range. The 27 major glaciers on its slopes form the largest mass of year-round ice in the United States outside Alaska.

Orographic effects of the Cascade Range produce dramatic patterns of precipitation along an east-west gradient through the park. Rain and snowfall are abundant on the west side, averaging about 250 cm per year at Paradise; most of this precipitation falls as snow. The abundant precipitation also produces many lakes, streams, and glaciers, which contribute to an abundant and diverse floral and faunal assemblage.

Mount Rainier National Park has an extensive network of rivers radiating from the mountain and the glacial activity has created nearly 200 lakes and ponds. The glaciers that remain on the mountain feed the rivers and some of the lakes with meltwaters. The lakes are distributed around the face of the mountain and extend from montane to alpine settings. The lakes at the higher elevations may remain ice-free only three to four months of the year.

## Deposition

Mount Rainier National Park is within 40 km of the Puget Sound urban zone and is downwind of the largest $SO_2$ source in Washington, the Centralia power plant. The four counties adjacent to MORA emit 56% of the State's $SO_2$ and 21% of the $NO_x$.

There is an NADP/NTN site located in LaGrande, Washington, west of MORA. This site has operated since April 1984. Figure 6-1 shows that sulfate wet deposition has fluctuated between 4-6 kg/ha/yr since data collection began. The initial decrease occurred as $SO_2$ emissions from Mount St. Helens decreased from 222,000 metric tons (244,000 tons) in 1980 to about 3,000 metric tons (3,300 tons) in 1988 (Eilers et al. 1994). Also, the ASARCO copper smelter in Tacoma discontinued operation in 1984, thereby eliminating over 100,000 tons per year of $SO_2$ emissions. After a slight increase in the middle and late 1980s, there was a slight decrease in the early 1990s.

**Figure 6-1: Sulfate wet deposition at LaGrande NADP site, 1984-2003. Source: NADP web site (http://nadp.sws.uiuc.edu/trends/trendplot.asp?action=trendplot.asp&siteid=WA21&inpanalyte=SO4-kg&PlotSize=Small)**

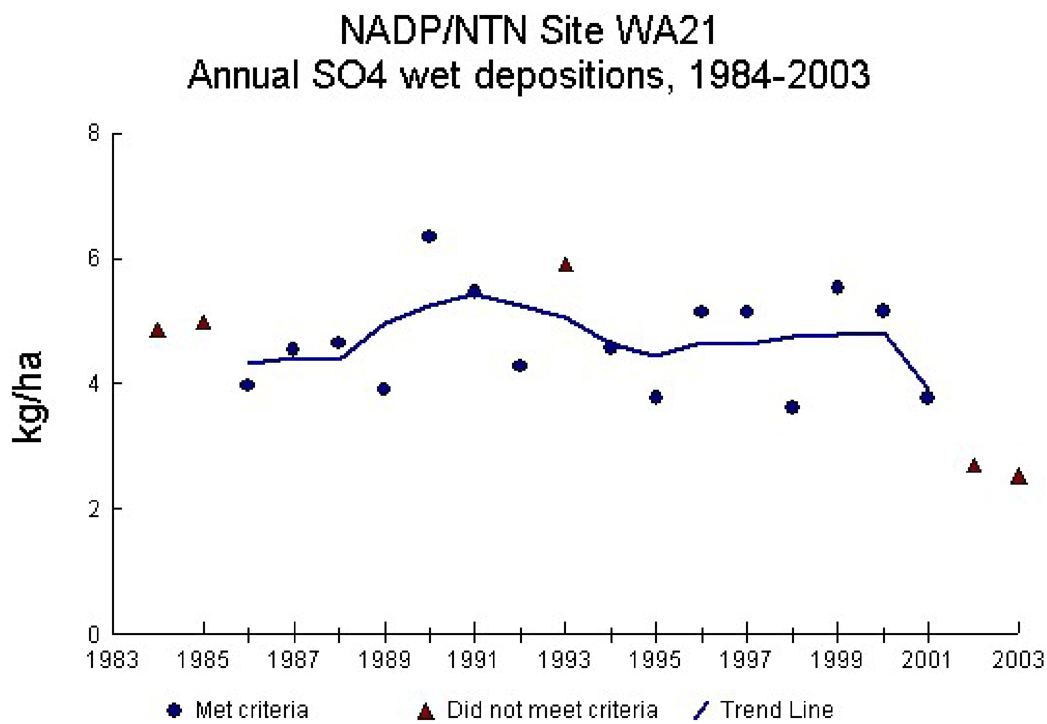
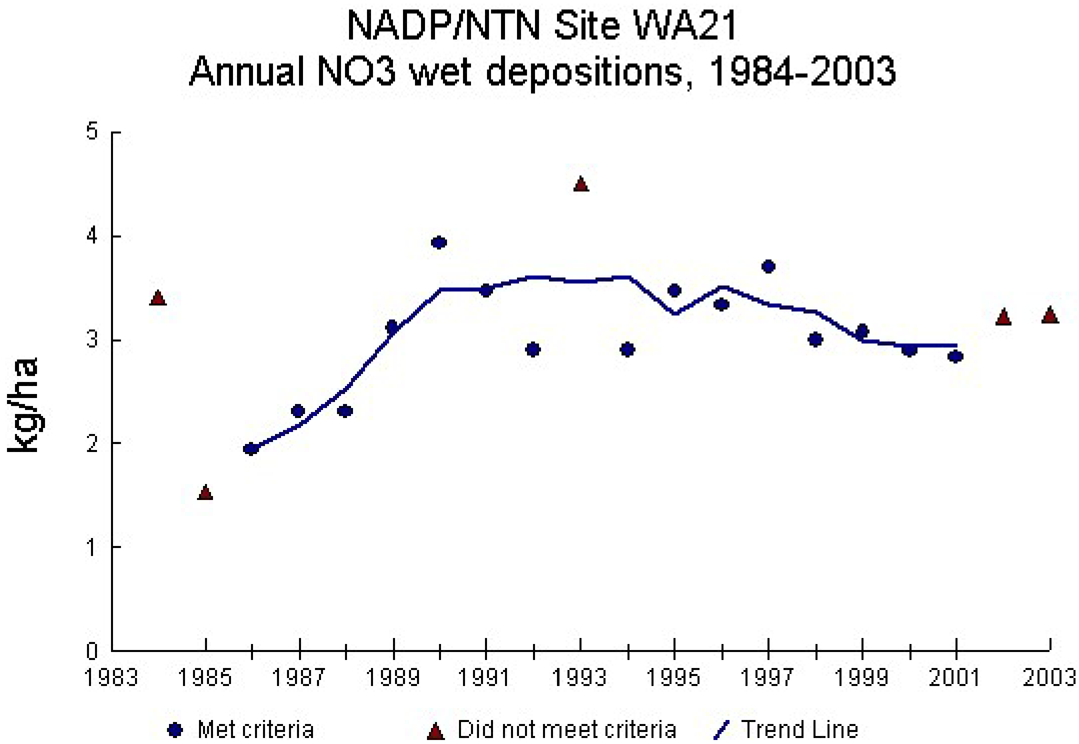



Figure 6-2 shows that nitrate wet deposition doubled from 2 kg/ha/yr in 1985 to 4 kg/ha/yr in 1990, and then declined in the last half of the 1990s to about 3 kg/ha/yr.

## Water Quality

Water quality studies in MORA have found different results between lakes and streams. Studies of lakes in MORA were conducted by Turney et al. (1986), Nelson and Baumgartner (1986), and Larson et al. (1992). Neither Turney et al. (1986) nor Nelson and Baumgartner (1986) found evidence for lake acidification in the MORA lakes. However, Nelson and Baumgartner (1986) found that the lakes sampled were "highly susceptible to acidification due to their diluteness and poor buffering capacity." The analysis by Larson et al. (1992) is consistent with the findings of the previously cited studies for MORA about lack of evidence of acidification.

**Figure 6-2: Nitrate wet deposition at LaGrande NADP site, 1984-2003. Source: NADP web site (http://nadp.sws.uiuc.edu/trends/trendplot.asp?action=trendplot.asp&siteid=WA21&inpanalyte=NO3-kg&PlotSize=Small)**




The Western Lake Survey (WLS) found Southwest Golden Lake, located on the west side of the park, to be among the most sensitive lakes sampled in the survey (Landers et al. 1987, Eilers et al. 1987). The lake is small (2 ha), relatively shallow (6 m), and is the type of lake that would be expected to respond quickly to changes in atmospheric deposition.

Studies of large streams in the park were initiated by Larson et al. (1990) who sampled the water quality in both glacial and non-glacial streams. In general, the larger streams in the park are relatively well buffered and are not expected to be sensitive to effects from atmospheric deposition. It is unknown if this sample can be extrapolated to the smaller streams.

## Aquatic Chemistry Data and DSS Results

### Horizon Report

The Horizon report was released for Mount Rainier NP in May 1995. The report contains information on 63 water bodies in the park. More water bodies exist, but were not sampled; 31% of the approximately 200 water bodies in MORA were listed in the report. 68% of water bodies in the report contained data relevant to the DSS. The report details 20 lakes, 35 streams, and 8 springs in Mount Rainier NP. Table 6-1 lists the number of sites that have data for each DSS component. The numbers indicate that data for the lakes is relatively complete, while data for the streams is quite sparse.

**Table 6-1: Chemistry Component Summary - MORA**

| | Total | Lakes | Streams | Springs |
|---|---|---|---|---|
| Number | 63 | 20 | 35 | 8 |
| Conductance | 43 | 20 | 16 | 7 |
| pH | 41 | 19 | 15 | 7 |
| ANC | 13 | 6 | 3 | 4 |
| DOC | 29 | 19 | 10 | 0 |
| Nitrate | 38 | 20 | 11 | 7 |
| Base Cations | 41 | 19 | 15 | 7 |
| Sulfate | 41 | 19 | 15 | 7 |

While 54% of stream sites had no data elements used by the DSS, 95% of the lake sites had six of or all seven of the data elements required by the DSS. Of the sites with data, 91% had 5 or more elements. This indicates that a standard set of chemical analyses was performed on many of water samples taken in the park.

**Table 6-2: Number of Elements Summary - MORA**

| # of Elements | Total | Lakes | Streams | Springs |
|---|---|---|---|---|
| 0 | 20 | 0 | 19 | 1 |
| 1 | 1 | 0 | 1 | 0 |
| 2 | 1 | 1 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 |
| 4 | 2 | 0 | 2 | 0 |
| 5 | 5 | 0 | 2 | 3 |
| 6 | 28 | 13 | 11 | 4 |
| 7 | 6 | 6 | 0 | 0 |

Of the 56 sites that had any data collection, including parameters not used by the DSS, 8 sites were last sampled in the 1970s, 47 in the 1980s, and 1 in the 1990s.

The lake data and the stream data were about the same age, with 95% of lakes and 75% of streams last sampled during the 1980s. At best, the data in this report is 15 years old and may not indicate current water chemistry conditions. It highlights the need for additional sampling to take place so that the DSS can have up to date data for making recommendations.

Of the 13 locations that had alkalinity data, sampling occurred only once at all of them. Additional sampling may be needed to gain information that the DSS can use to make more accurate assessments.

## ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

### *Mean ANC*

Of the 13 sampling locations which contained data for ANC calculations, only 1 had a mean ANC below 50 μeq/L. This is site MORA0033, Golden Lakes Southwest, which had a mean ANC of 12 μeq/L.

Figure 6-3 contains a graph of the frequency distribution of mean ANC values in Mount Rainier NP.

### *Minimum ANC*

Since there is only one alkalinity measurement at each location, the results for mean ANC and minimum ANC values are the same. Golden Lake Southwest, MORA0033, is the only site that had an ANC below 50 μeq/L.

Figure 6-4 contains a graph of the frequency distribution of minimum ANC values in Mount Rainier NP.

**Figure 6-3: Frequency Distribution of Mean ANC Values - MORA**

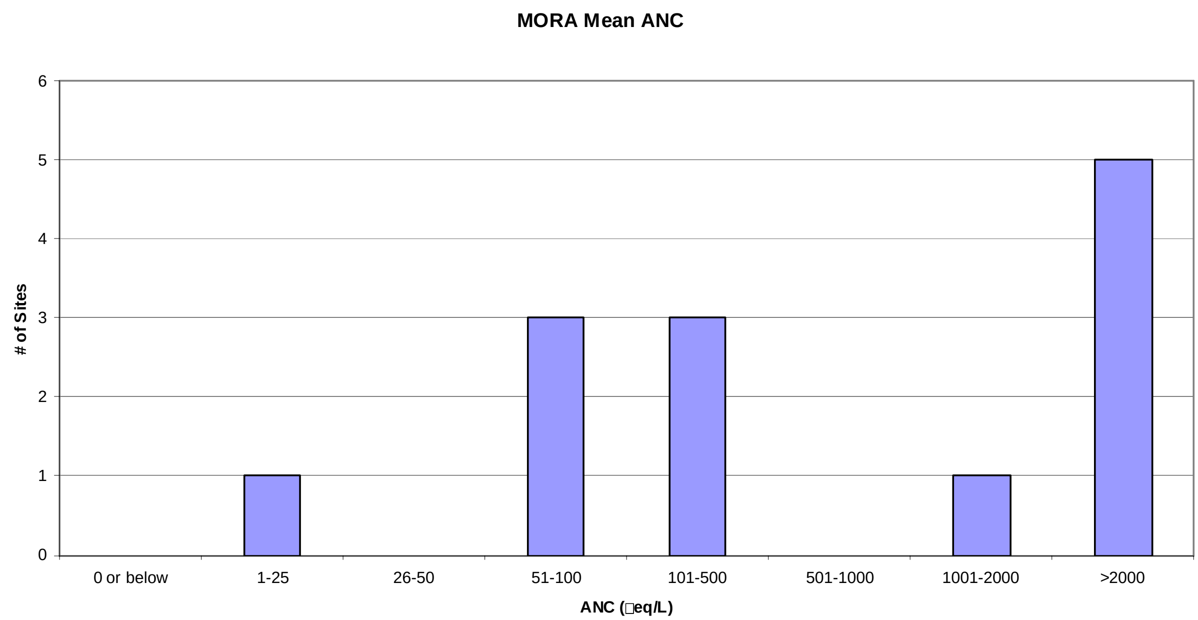
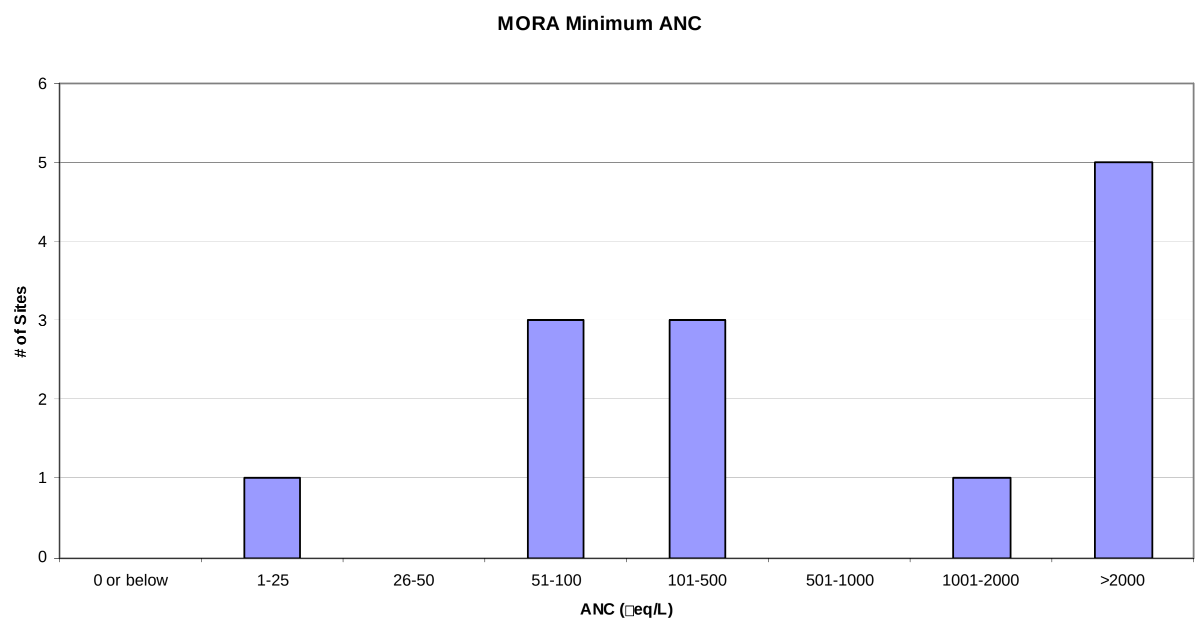



**Figure 6-4: Frequency Distribution of Minimum ANC Values - MORA**



## Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

### *Lakes - Average Water Chemistry Values*

Table 6-3 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in Mount Rainier NP and Figure 6-5 includes graphical representations of this data.

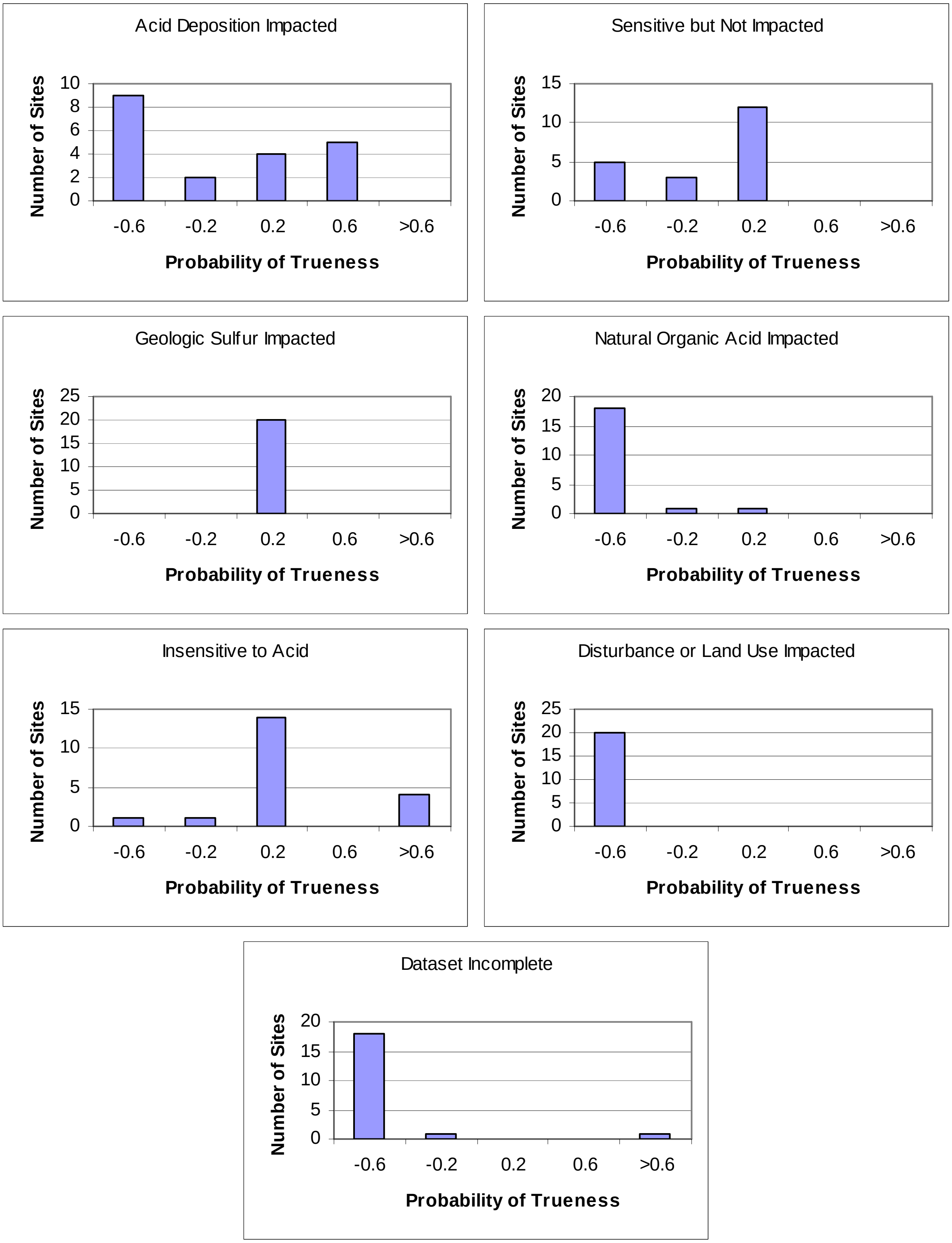
One lake, MORA0063, Lonesome Lake, had only two data parameters for the DSS (specific conductance and nitrate concentration). The DSS makes recommendations with no certainty for all of the categories for this lake except for Disturbance or Land Use Impacted.

**Table 6-3: DSS Results for Average Lake Values - MORA**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 9 | 5 | 0 | 18 | 1 | 20 | 12 |
| -0.59 to -0.20 | 2 | 3 | 0 | 1 | 1 | 0 | 7 |
| -0.19 to 0.20 | 4 | 12 | 20 | 1 | 14 | 0 | 0 |
| 0.21 to 0.60 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 4 | 0 | 1 |

Of the lakes for which the DSS made an assessment about acid deposition, 11 are rated as not being acid deposition impacted (false in the ‘Acid Deposition Impacted’ category), 9 with a high degree of certainty. These lakes have low nitrate and sulfate concentrations or high ANC values and base cation concentrations. The lakes identified as acid deposition impacted (true in the ‘Acid Deposition Impacted’ category) are poorly buffered as indicated by low specific conductance (≤ 12 μS/cm) and few base cations (≤ 100 μeq/L). Low specific conductance suggests that lakes may already have been impacted by acid deposition (Sullivan et al., in review). These five locations are Marsh Lake (MORA0016), Unnamed Lake (16/07-34) (MORA0031), Golden Lake (MORA0036), Mowich Lake (MORA0045), and Chenuis Lake (MORA0049).

**Figure 6-5: Charts of DSS Results for Average Lake Values - MORA**




The DSS classified 8 lakes as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These lakes are characterized by high ANC values (> 80 μeq/L) or high base cation concentrations (> 200 μeq/L). No lakes were found to be sensitive but not impacted (true in the "Sensitive but Unimpacted' category). The DSS did not make an assessment about a majority of locations in this category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

All 19 of the lakes with data were found to be not impacted by natural organic acid (false in 'Natural Organic Acid Impaired' category). This is due to the low levels of DOC found in the samples (< 3 μeq/L).

Four lakes are insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (> 80 μeq/L). Two lakes were found to be sensitive to potential changes in acidic conditions due to their low buffering capacity (false in the 'Insensitive to Acid' category). These locations had specific conductance values < 10 μS/cm and base cation concentrations < 100 μeq/L. The two sensitive lakes are Golden Lakes Southwest (MORA0033) and Chenuis Lakes Southern (MORA0048). The DSS did not make an assessment about a majority of the locations in this category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

No lakes were found to suffer from the results of disturbance or land use (i.e., were false in the 'Disturbance or Land Use Impacted' category). In all cases, the nitrate concentration was ≤ 2 μeq/L.

The DSS evaluates all of the locations in terms of the completeness of the input data. The six locations containing all seven inputs have complete datasets. The remaining locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Lakes – Extreme Water Chemistry Values*

Table 6-4 lists the results of the DSS for extreme values of water chemistry parameters in lakes in MORA. Figure 6-6 graphically represents these results.

**Table 6-4: DSS Results for Extreme Lake Values - MORA**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 9 | 5 | 0 | 18 | 1 | 20 | 18 |
| -0.59 to -0.20 | 2 | 3 | 0 | 1 | 1 | 0 | 1 |
| -0.19 to 0.20 | 4 | 12 | 20 | 1 | 14 | 0 | 0 |
| 0.21 to 0.60 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 4 | 0 | 1 |

The DSS result distribution for extreme lake values are exactly the same as that for average lake values. This occurred because results at all of the lake locations came from a single test at that location. Therefore, the mean value for a parameter and its extreme value are the same.

*Streams - Average Water Chemistry Values*

Table 6-5 lists the results of the Synthesis DSS for average water chemistry values at streams in Mount Rainier NP and Figure 6-7 represents this data graphically.

**Table 6-5: DSS Results for Average Stream Values - MORA**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 14 | 15 | 0 | 14 | 0 | 7 | 10 |
| -0.59 to -0.20 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| -0.19 to 0.20 | 0 | 1 | 16 | 1 | 13 | 5 | 2 |
| 0.21 to 0.60 | 2 | 0 | 0 | 1 | 0 | 0 | 2 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 3 | 4 | 1 |

One stream site had only one data parameter for the DSS. Huckleberry Creek, MORA0057, had only specific conductance data. The DSS makes recommendations with no certainty for all of the categories for these streams except for Acid Deposition Impacted and Sensitive but Unimpacted.

**Figure 6-6: Charts of DSS Results for Extreme Lake Values - MORA**

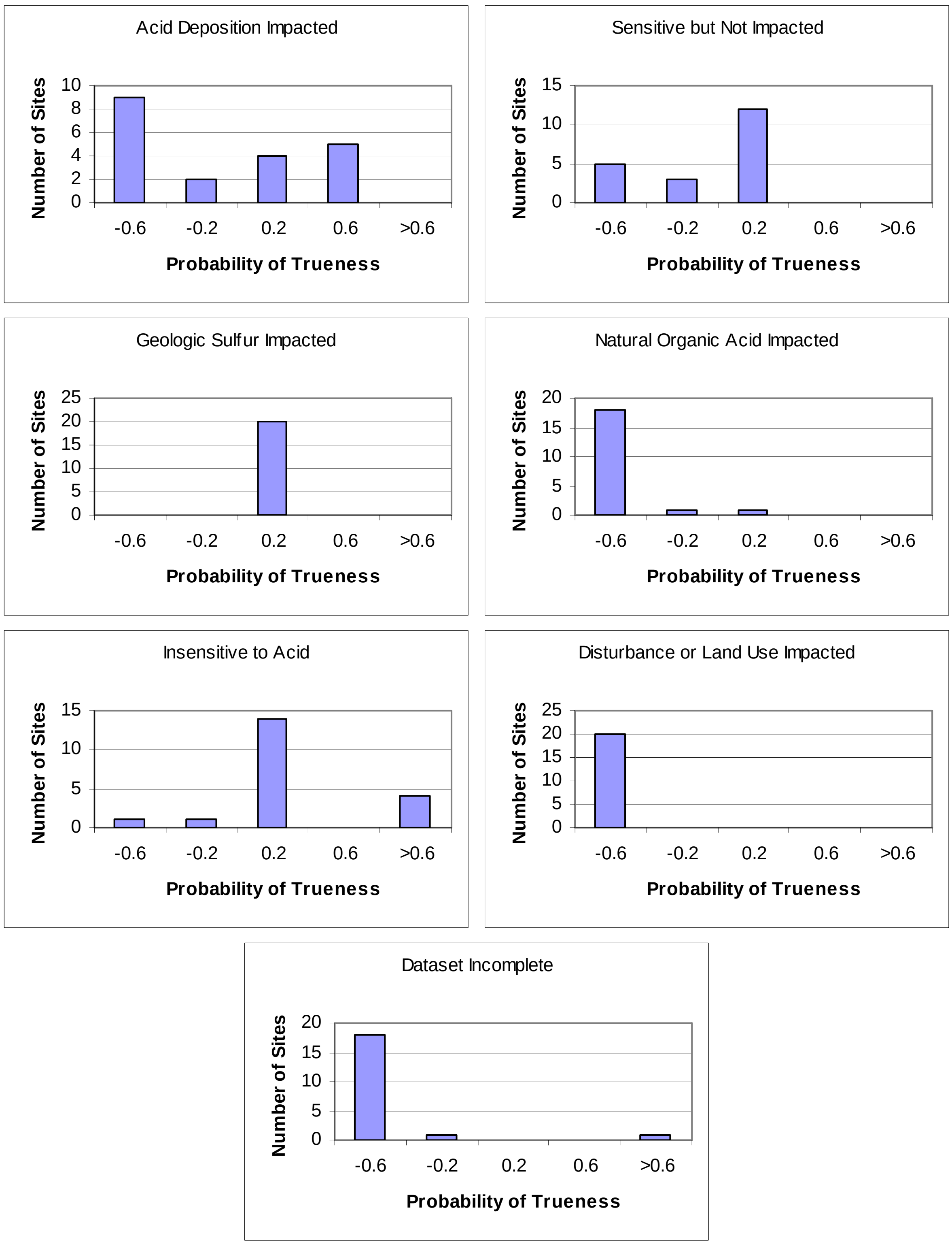
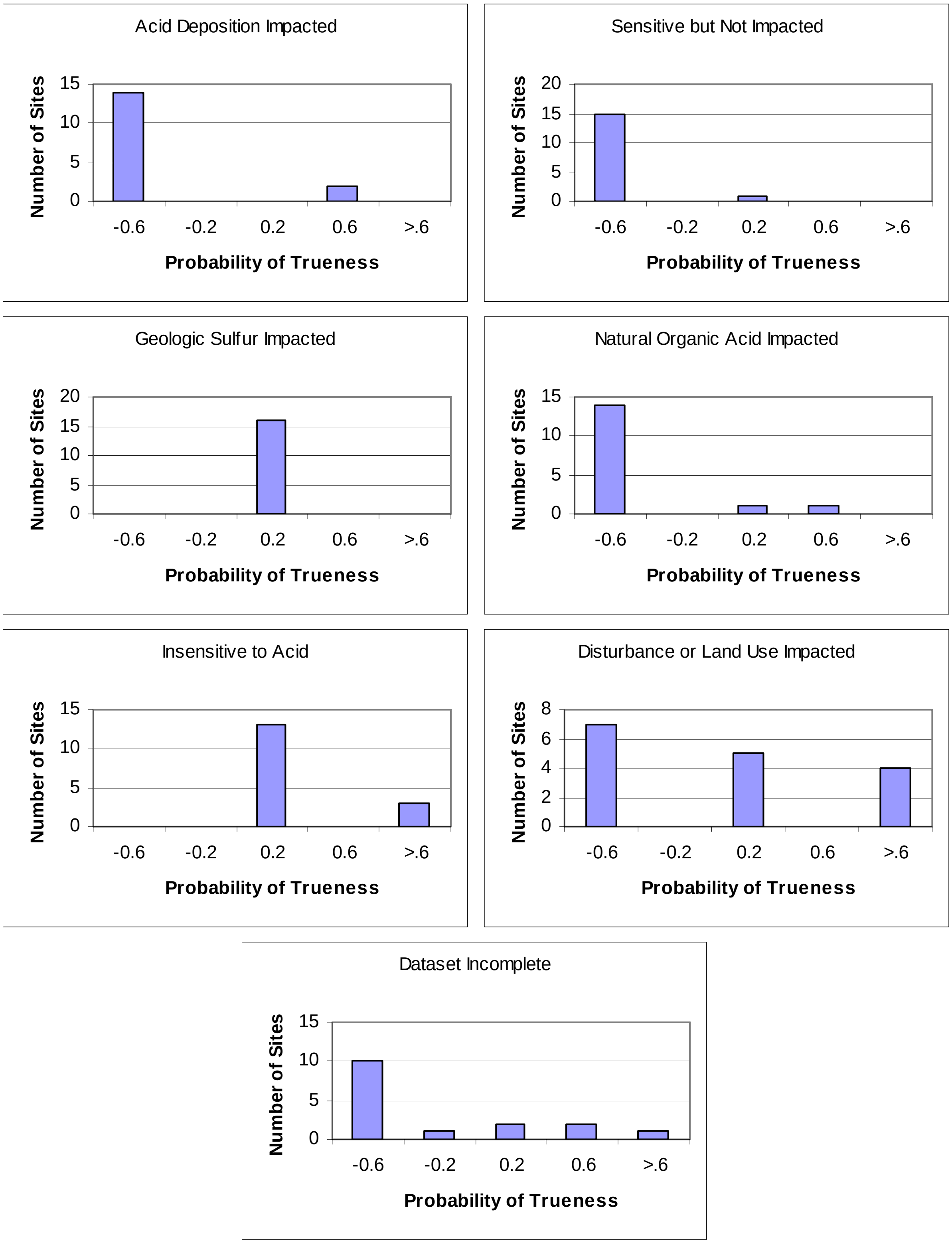


**Figure 6-7: Charts of DSS Results for Average Stream Values - MORA**



Of the 16 streams for which the DSS made an assessment, 14 were found to not be impacted by acid deposition, (false in the ‘Acid Deposition Impacted’ category). With one exception, these streams have high buffering capabilities, as indicated by high ANC values (> 100 μeq/L), high specific conductance values (> 20 μS/cm), and/or high base cation concentrations (> 200 μeq/L). Winthrop Cold Stream (MORA0039) does not have high buffering capacity; however, there is no evidence that it has been impacted by acid deposition. Two streams were found to be impacted by acid deposition (true in the ‘Acid Deposition Impacted’ category). Ohanapecosh River (MORA0027) and Carbon River (MORA0050) are both characterized by low base cation concentrations (< 180 μeq/L) and high nitrate concentrations (> 6 μeq/L).

Fifteen streams are rated false in the ‘Sensitive but Unimpacted’ category. This is mainly due to the high buffering capacity of these streams; the 14 streams not impacted by acid deposition fall into this category for the reasons listed above.

The DSS did not make an assessment about any of the locations in the ‘Geologically Sulfur Impaired’ category. This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category.

Fourteen streams do not have evidence of impact due to organic acids (false in the ‘Natural Organic Acid Impaired’ category). Again, this is largely due to the high buffering capacity of streams in MORA. One stream was determined probably to be impacted by organic acids, Withrop Cold Stream (MORA0039).

No streams are considered sensitive to acid (false in the ‘Insensitive to Acid’ category). For a majority of the stream locations, the DSS did not make an assessment in this category. This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category. Three streams were found to be insensitive to acid (true in the ‘Insensitive to Acid’ category). All three of these locations had ANC values > 350 μeq/L.

The DSS determined 7 streams were not impacted due to disturbance or land use purposes (false in the ‘Disturbance or Land Use Impacted’ category). In all cases, the nitrate concentration was ≤ 7 μeq/L. Four sites with nitrate concentrations > 19 μeq/L were determined to be disturbance or land use impacted by the DSS (true in the ‘Disturbance or Land Use Impacted’ category). Nitrate concentrations at the Muddy Fork of the Cowlitz River (MORA0021), 25.8 μeq/L, the Nisqually River (MORA0022), 19.4 μeq/L, the Inter Fork of the White River (MORA0040), 38.7 μeq/L, and the Carbon River (MORA0050), 24.2 μeq/L, are high enough that the DSS was fairly confident that the impacts found at this location came from anthropogenic inputs.

The DSS evaluates all of the locations in terms of the completeness of the input data. The 11 sites with six inputs are reasonably certain to have complete datasets.

The other 5 locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to acid.

*Streams - Extreme Water Chemistry Values*

Table 6-6 contains the results of the Synthesis DSS of extreme water chemistry value for streams in Mount Rainier NP. Figure 6-8 shows the data graphically.

**Table 6-6: DSS Results for Extreme Stream Values - MORA**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 14 | 15 | 0 | 13 | 0 | 7 | 10 |
| -0.59 to -0.20 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| -0.19 to 0.20 | 0 | 1 | 16 | 1 | 13 | 5 | 2 |
| 0.21 to 0.60 | 2 | 0 | 0 | 2 | 0 | 0 | 2 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 3 | 4 | 1 |

The DSS result distribution for extreme stream values are exactly the same as that for average stream values. This occurred because results at all of the stream locations came from a single test at that location. Therefore, the mean value for a parameter and its minimum value are the same.

## Analysis

Three of the main findings from previous water quality research within MORA were (1) lakes have low buffering capacity, based primarily on low ANC values; (2) streams have high buffering capacity, based primarily on high ANC values; and (3) park waters had not yet been impacted by acidification. This section will review these findings in terms of the DSS results.

A body of water that has an ANC of below 50 μeq/L is at risk to impact from exposure to acid. Only 1 water body had an ANC value that met this criterion. It is listed in Table 6-7:

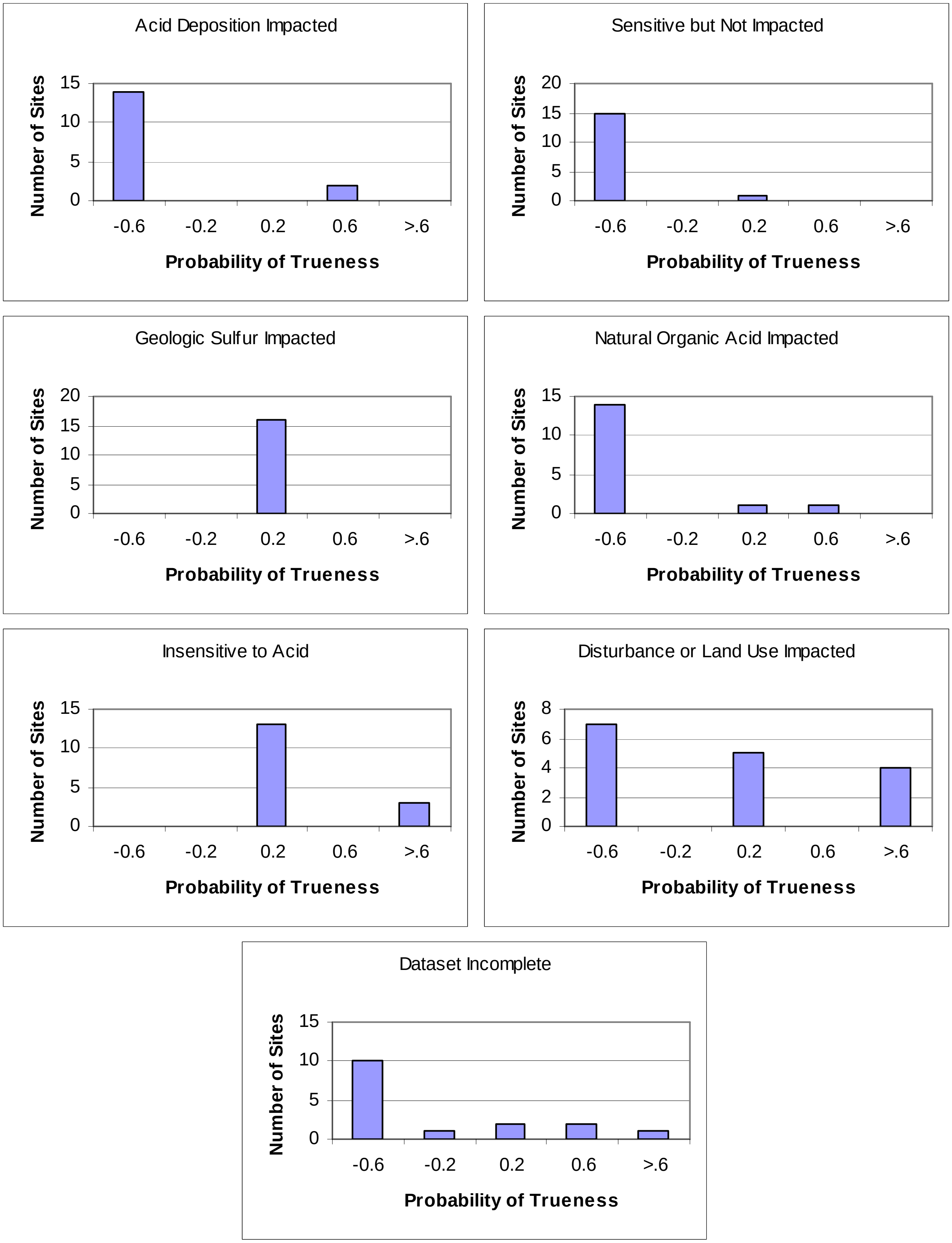
**Table 6-7: MORA Water Bodies with Minimum ANC <50 μeq/L**

| Location ID | Location Name | Sample Type | Impact(s)* | # Obs | Last Sampled** |
|---|---|---|---|---|---|
| MORA0033 | Golden Lake Southwest | Lake | Sensitive to Acid | 1 | 1985 |

*For the Acid Impacted and Sensitive/Unimpaired categories, the DSS returned a 'true' value for these locations; for the Insensitive to Acid category, the DSS returned a 'false' value.

**"Last Sampled" refers to the last documented sample from the Horizon Report used in this analysis.

**Figure 6-8: Charts of DSS Results for Extreme Stream Values - MORA**



This location was identified in the Western Lake Survey as being highly sensitive to future acid deposition. None of the other locations sampled had ANC values below 50 μeq/L. Several factors can account for this apparent discrepancy. First is that ANC data for many sensitive locations simply may not be present in the Horizon report. Only 63 water bodies of the more than 200 contained in MORA are listed in the report. Of these, only 13 contain ANC data. Second is that only one ANC measurement was obtained at each location with ANC data, taken in either late August, September, or early October. Conditions on the sampling date may not indicate the sensitive nature of MORA lakes that occur at other times throughout the year. Also, other data in the Horizon Report, such as low base cation concentrations (< 100 μeq/L) and low specific conductance values (< 10 μS/cm) suggest that MORA lakes have low buffering capabilities.

The data indicate that streams in MORA have high buffering capacity. Only 3 of the 16 stream sites had ANC data; at all of these locations, ANC values were > 350 μeq/L. Other data, such as high base cation concentrations (> 200 μeq/L) and high specific conductance values (> 20 μS/cm) also indicate high stream buffering capacity.

In contrast to previous research, which found no impacted waters, the DSS considered 14 water bodies to be acid impacted or sensitive to future acid deposition based on extreme stream values. These locations are listed in Table 6-8. These locations are where additional sampling should take place. Among these waters, Golden Lake Southwest (MORA0033) is a high priority due to its high potential sensitivity to acidity as indicated by its extremely low ANC value (12 μeq/L).

**Table 6-8: Potentially Sensitive MORA Water Bodies Based on Extreme Water Chemistry Values**

| Location ID | Location Name | Flagged Categories* | Last Sampled** |
|---|---|---|---|
| MORA0016 | Marsh Lake | Acid Deposition Impacted | 1983 |
| MORA0021 | Muddy Fork Cowlitz River | Disturbance/Land Use Impacted | 1981 |
| MORA0022 | Nisqually River above Longmire | Disturbance/Land Use Impacted | 1981 |
| MORA0025 | Paradise Cold Stream | Natural Organic Acid Impacted | 1982 |
| MORA0027 | Ohanapecosh River near Chinook Creek | Acid Deposition Impacted | 1981 |
| MORA0031 | Unnamed Lake (16/07-34) | Acid Deposition Impacted | 1983 |
| MORA0033 | Golden Lake, Southwest | Sensitive to Acid | 1985 |
| MORA0036 | Golden Lake | Acid Deposition Impacted | 1983 |
| MORA0039 | Winthrop Cold Stream | Natural Organic Acid Impacted | 1982 |
| MORA0040 | Inter Fork above White River | Disturbance/Land Use Impacted | 1981 |
| MORA0045 | Mowich Lake | Acid Deposition Impacted | 1983 |
| MORA0048 | Chenuis Lake (Southern) | Sensitive to Acid | 1985 |
| MORA0049 | Chenuis Lake | Acid Deposition Impacted | 1983 |
| MORA0050 | Carbon River at Ipsut Creek Campground | Acid Deposition Impacted<br>Disturbance/Land Use Impacted | 1981 |

*For the Disturbance/Land Use Impacted and Natural Organic Acid Impacted categories, the DSS returned a ‘true’ value for these locations; for the Insensitive to Acid category, the DSS returned a ‘false’ value.

**”Last Sampled” refers to the last documented sample from the Horizon Report used in this analysis.

Seven of the 14 locations were considered to be impacted by acid deposition of nitrate and sulfur. At each of these locations, buffering capacity was low. Nitrate levels consistent with possible atmospheric deposition (> 6 μeq/L) were found at the 2 stream sites, Ohanapecosh River (MORA0027) and Carbon River (MORA0050). At the five lake locations, Marsh Lake (MORA0016), Unnamed Lake (16/07-34) (MORA0031), Golden Lake (MORA0036), Mowich Lake (MORA0045), and Chenuis Lake (MORA0049), low specific conductance suggests that these waters may already have been impacted by acid deposition.

Extremely high nitrate concentrations (> 19 μeq/L) were found at the 4 stream locations identified as impacted by disturbance or land use. Nitrate concentrations at the Muddy Fork of the Cowlitz River (MORA0021), 25.8 μeq/L, the Nisqually River (MORA0022), 19.4 μeq/L, the Inter Fork of the White River (MORA0040), 38.7 μeq/L, and the Carbon River (MORA0050), 24.2 μeq/L, are high enough that the DSS was fairly confident that the impacts found at this location came from anthropogenic inputs or disturbance and land use sources. Given that its nitrate concentration is relatively high, the DSS has more confidence that the Carbon River location is disturbance or land use impacted rather than acid deposition impacted.

The two locations considered sensitive to acid have low buffering capacity. Both sites have low levels of specific conductance; Chenuis Lake - Southern (MORA0048) reported conductance at 8 μS/cm and at Golden Lake - Southwest (MORA0033), conductance was measured at 6 μS/cm. As listed in Table 6-7 above, Golden Lake – Southwest was the only park water body to have an ANC of less than 50 μeq/L (12 μeq/L).

Two streams were considered probably to be acid impacted by natural organic acids. Both Paradise Cold Stream (MORA0025) and Withrop Cold Stream (MORA0039) had low pH (≤ 6) and were not impacted by nitrogen or sulfur deposition.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

Compared to other parks, a consistent set of water chemistry tests were performed on the samples taken from MORA. Thirty of the 36 locations (83%) that had data contained six or seven of the data elements used by the DSS. The classifications made at these locations are likely based on adequate data.

It is difficult to know how applicable the classifications reported by the DSS for Mount Rainier NP are to the current state of the water bodies. Just 1 of the 63 sites that had any data collected after 1990. At best, the data in this report is 15 years old and may not indicate current water chemistry conditions. It highlights the need for additional sampling to take place or be reported on so that the DSS can utilize current data for making recommendations.

It may be more important to sample sensitive sites or areas more frequently than to sample all water bodies, especially those deemed not to be susceptible to acid deposition. This would assist in determining if these water bodies are subject to episodic or chronic acidification.

## Conclusion

Pollution levels have substantially increased over the last 150 years. Sulfate and nitrate are the most important anionic components in acidic deposition. The air quality in the Pacific Northwest region is very good compared to other areas of the U.S. A regional NPS report showed that this region had low levels of S deposition (0.5 to 4 kg S/ha/yr) and N deposition (0.5 to 2.4 kg N ha/yr) during the early 1990s. However, emissions from areas outside the park, such as Seattle and Vancouver, British Columbia, have the potential to impact the park.

Pollution effects are of concern in this region because its lakes are likely among the most sensitive aquatic systems anywhere in the world. Acidic deposition of both S and N may cause chronic or episodic acidification of surface waters at low levels of deposition.

This evaluation focuses on Mount Rainier NP (MORA). The water quality data was extracted from the Horizon report, completed in May 1995. Values for specific conductance, pH, ANC, DOC, nitrate, the sum of base cations, and sulfate were obtained. These reports may not contain data for the most sensitive water bodies; for example, the report contains only 31% of the approximately 200 water bodies in MORA. Therefore, the analysis may not give a true representation of the sensitivity or level of impact by acid deposition for the entire park.

A body of water that has an ANC of below 50 μeq/L is at risk to impact from exposure to acid. Only 1 of the 9 lakes and streams that had ANC values met this criterion: Golden Lake – Southwest (MORA0033). This location requires particular attention because it may be sensitive to future acid deposition. Given its low buffering capacity, relatively small increases in acid concentrations may impact this location.

Several of the waters in MORA probably have been affected by acid deposition. Seven water bodies showed probable impact by acid deposition. Two stream sites, Ohanapecosh River (MORA0027) and Carbon River (MORA0050), had high nitrate levels (> 6 μeq/L). The nitrate level in the Carbon River may be too high to be from acid deposition alone. Five lake locations, Marsh Lake (MORA0016), Unnamed Lake (16/07-34) (MORA0031), Golden Lake (MORA0036), Mowich Lake (MORA0045), and Chenuis Lake (MORA0049), had low specific conductance, suggesting that these waters may already have been impacted by acid deposition.

Five other locations show probable acid impact from disturbance or land use or from organic acids: Muddy Fork of the Cowlitz River (MORA0021), Nisqually River (MORA0022), Paradise Cold Stream (MORA0025), Withrop Cold Stream (MORA0039), and Inter Fork of the White River (MORA0040). Two other locations may lack the buffering capacity to deal with future acidity: Golden Lake - Southwest (MORA0033), as listed above, and Chenuis Lake - Southern (MORA0048).

The DSS result distribution for extreme water values are largely the same as that for average lake values. Many results contain data from one or two samples. In these cases, the result is 'extreme' values that are the same as the mean values. With so few samples, it is difficult to ascertain if the data assembled is representative of the water body in question.

Data issues that affected this analysis include a general lack of data, infrequent sampling, and old data. Only 52% of water bodies in the report contained data relevant to the DSS. In addition, 37% of sites with data had only one data element used by the DSS. This lack of data left the DSS unable to report with any certainty most stream locations with respect to being impacted by high organic levels, high nitrogen levels, likely due to anthropogenic causes, and not being sensitive to acid due to high buffering capabilities. Such a large degree of uncertainty makes it difficult to make an overall recommendation for the park concerning water quality management decisions.

Data representing present conditions are needed. All but one of the MORA waters were sampled after 1990. The Horizon report is 10 years old. It is likely the condition of these waters has changed during this period. Ongoing monitoring and research can now provide additional data to characterize MORA lakes and streams.

While an overall recommendation for the park cannot be made, the DSS has identified 14 bodies of water that may require attention. Given resource limitations, it is important to prioritize potential and already existing problem areas at specific bodies of water, to collect more samples at these locations, and to run a standardized set of chemical analyses against these samples. The one location that had an ANC value below 50 $\mu$eq/L, Golden Lake, tops the priority list. The other waters that were currently or potentially impacted under extreme water chemistry conditions should be monitored for changes.

# Chapter 7 - North Cascades National Park

## Background

The information in this section was taken from the Status of Air Quality and Effects of Atmospheric Pollutants on Ecosystems in the Pacific Northwest Region of the National Park Service (Eilers et al. 1994). The complete report is available on the web at the following site:

http://www2.nature.nps.gov/air/pubs/PacificNW.Review/index.html

## Description

Created on October 2, 1968 and nicknamed the "American Alps", North Cascades National Park encompasses 271,700 ha of rugged mountain scenery in north-central Washington, about 80 km east of Bellingham. Extending from Canada's Fraser River south beyond Oregon, the Cascades contribute greatly to shaping the Pacific Northwest's climate and vegetation.

The area has extensive topographic relief. Mountain summits rise abruptly 1800-2600 m above the valley floor. This steep topography and orographic climatic influences produce a diverse range of biogeoclimatic zones and ecosystems. The average annual precipitation ranges from 280 cm on the western side, to only 90 cm on the eastern side of the park complex. The heavy precipitation and cold, harsh winters of the area have produced an abundance of alpine lakes, ice caps, and more than 300 glaciers.

The park contains three reservoirs: Ross, Diablo, and Gorge Lakes. These reservoirs are an important recreational element in the park because of their accessibility. In contrast, the 245 natural lakes in the park are in subalpine and alpine settings, and are accessible only on foot. The natural lakes and stream valleys were formed by glacial action which is still evident throughout the park.

The emissions in the three counties adjacent to NOCA and King County to the south indicate that nitrogen dioxide and sulfur dioxide values generally were low in the region and no exceedances occurred for either of these primary standards. However, emissions from areas outside the park, such as Seattle (King County) and Vancouver, British Columbia, have the potential to impact the park.

## Deposition

Total annual S and N deposition is difficult to estimate at the more sensitive sites, which tend to be located at higher elevations in remote regions of the parks. Extrapolation of low-elevation deposition monitoring data (e.g., NADP/NTN sites) to these high-elevation sites has been done with some success. Methods combining data from wet deposition, dry deposition, snow cores, bulk deposition, throughfall, and cloudwater chemistry can produce estimates of site-specific total deposition.

NOCA has a NADP/NTN site located at Marblemount immediately to the west of the park at an elevation of 123 m. The site has operated since February 1984. Precipitation-weighted mean annual chemistry at this site shows that the site receives precipitation with slightly elevated levels of $SO_4^{2-}$ and $NO_3^-$. As a result, pH is slightly less than that experienced at other Pacific Northwest sites such as the Hoh Valley in OLYM. The NADP site at Marblemount probably is representative of deposition in the low elevations on the west side of the park. Precipitation volume increases at higher elevations on the west side of the park and decreases dramatically to the east.

Figure 7-1 shows that sulfate wet deposition has declined since records were first kept in 1984 to 1987, and again after 1990. The first reduction in sulfur dioxide ($SO_2$) emissions occurred in 1985 when the ASARCO smelter in Tacoma discontinued operation, resulting in a reduction of 143,000 tons $SO_2$ per year (WDOE 1993).

**Figure 7-1: Sulfate deposition at Marblemount NADP site, 1984-2003. Source: NADP web site (http://nadp.sws.uiuc.edu/trends/trendplot.asp?action=trendplot.asp&siteid=WA19&inpanalyte=SO4-kg&PlotSize=Small)**

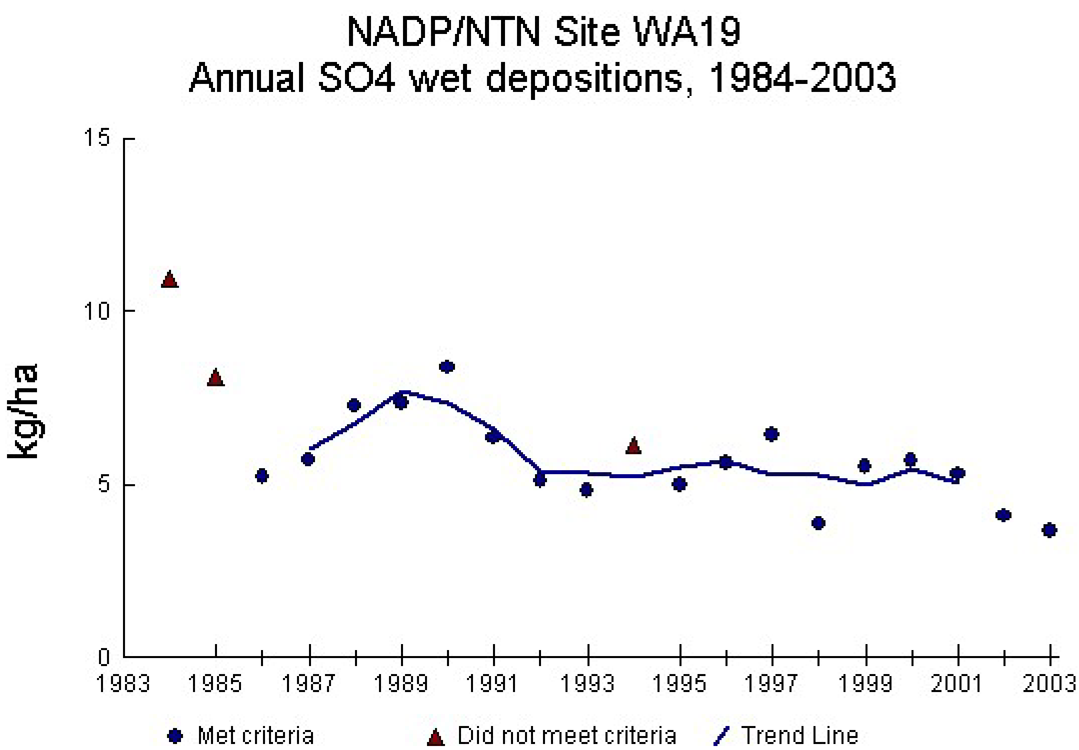
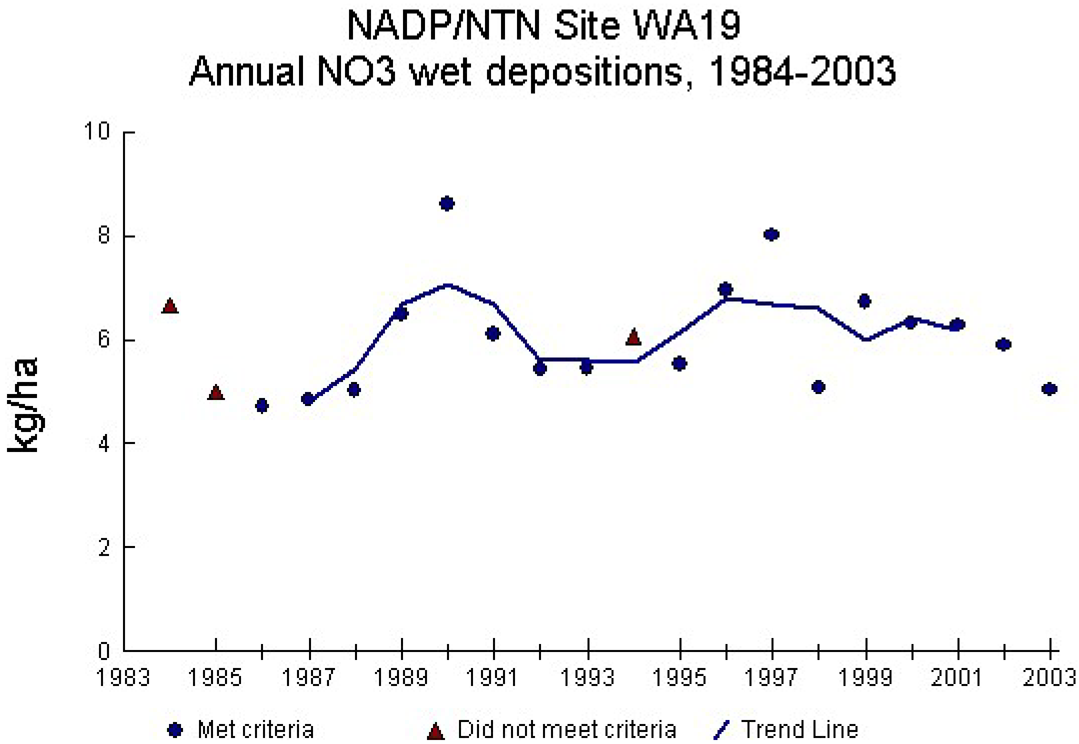



Figure 7-2 shows a cycle of increases and decreases of nitrate wet deposition since 1984. With some exceptions, these values remain between 4-7 kg/ha/yr of nitrate.

**Figure 7-2: Nitrate deposition at Marblemount NADP site, 1984-2003. Source: NADP web site (http://nadp.sws.uiuc.edu/trends/trendplot.asp?action=trendplot.asp&siteid=WA19&inpanalyte=NO3-kg&PlotSize=Small)**




## Water Quality

Because some parts of the park are extremely difficult to access, considerable monitoring and research work remains to be done, particularly with respect to detailed chemical characterization of the alpine lakes and streams. The complex mineralogy of NOCA, as evidenced in the wide range of the ratio of dissolved Ca:Na in the lakes in the region makes the task of predicting effects of atmospheric deposition very difficult.

For lake data, the major reservoirs in NOCA, creations of the dams impounding Ross, Diablo, and Gorge Lakes, have been studied. Due to their relatively high alkalinity (500 to 800 µeq/L), the studies concluded that the reservoirs are not highly relevant for air-pollution effects. A natural lakes inventory is 'complete' for 115 of 245 natural lakes. However, the inventory does not include complete chemistry data. Major ion chemistry data is available for only approximately 20 lakes.

Data from Brakke (1984) and Liss et al. (1991) illustrate the existence of some low-alkalinity (less than 10 µeq/L) waters in the park that may be very susceptible to acidification. In contrast, Funk et al. (1987) studied baseline water quality in lakes Ross, Diablo, and Chelan and found relatively high alkalinity (500 to 800 µeq/L).

Unlike many other lakes in the West which have moderately high $Na^+$ concentrations, many NOCA lakes had comparatively high $Ca^{2+}$ concentrations, supporting the results of Drever and Hurcomb (1986) who studied weathering in South Cascade. Excess $SO_4^{2-}$ in one of the lakes was attributed to weathering of pyrite present in the watershed.

Little is known about the seasonal variation of these lakes and streams, and virtually no data have been collected on episodic responses associated with snowmelt. The highest priority for seasonal and episodic response again is on the west side of the park because of the much greater precipitation and likelihood of enhanced deposition of S and N in cloudwater. Lakes and streams receiving meltwater from glaciers may be less sensitive because of the high physical weathering rates associated with glacial action.

## Aquatic Chemistry Data and DSS Results

### Horizon Report

The Horizon report was completed for North Cascades NP in May 1995. Although the park has approximately 245 lakes and many streams, the report contains information on only 82 water bodies in the park (19 lakes and 63 streams). More water bodies exist, but were not sampled; for example, only 7.8% of lakes in NOCA were listed in the report. Only 52% of water bodies in the report contained data relevant to the DSS. Table 7-1 lists the number of sites that have data for each DSS component. The numbers indicate that data for the sampled lakes is relatively complete in terms of the DSS requirements, while data for the streams is quite sparse.

**Table 7-1: Chemistry Component Summary - NOCA**

| | Total | Lakes | Streams |
|---|---|---|---|
| Number | 82 | 19 | 63 |
| Conductance | 39 | 14 | 25 |
| pH | 27 | 14 | 13 |
| ANC | 21 | 14 | 7 |
| DOC | 12 | 12 | 0 |
| Nitrate | 25 | 17 | 8 |
| Base Cations | 20 | 12 | 8 |
| Sulfate | 20 | 12 | 8 |

In addition, 37% of sites with data had only one data element used by the DSS, leaving two-thirds of all reported sites in North Cascades NP with one element or less, including 79% of streams. In contrast, 63% of the lake sites had all of the data elements required by the DSS. Table 7-2 shows the number of sites that had a given number of data elements required by the DSS.

**Table 7-2: Number of Elements Summary - NOCA**

| # of Elements | Total | Lakes | Streams |
|---|---|---|---|
| 0 | 39 | 2 | 37 |
| 1 | 16 | 3 | 13 |
| 2 | 3 | 0 | 3 |
| 3 | 2 | 0 | 2 |
| 4 | 3 | 2 | 1 |
| 5 | 2 | 0 | 2 |
| 6 | 5 | 0 | 5 |
| 7 | 12 | 12 | 0 |

Of the 43 sites that had any data collection, 30 sites were last sampled in the 1970s and 13 in the 1980s. The lake data was newer than the stream data. Sixty-three percent of lakes had their last samples taken during the 1980s, while the latest sampling at 96% of streams occurred in the 1970s. At best, the data in this report is 15 years old and may not indicate current water chemistry conditions. Of the 21 locations that had alkalinity data, sampling occurred once at 62% of them, including 86% of lakes. However, at 86% of streams, sampling took place more than once.

## ANC Results

One of the parameters used in the DSS is alkalinity, which is a measure of how well the water body can buffer additions of acid. A standard measure of alkalinity is ANC or acid neutralizing capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body may be sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and characterizes the most sensitive condition for that water body.

### *Mean ANC*

Of the 21 sampling locations which contained data for ANC calculations, 24% of them had mean ANCs below 50 μeq/L. These locations are listed in Table 7-3.

**Table 7-3: Locations with mean ANCs below 50 μeq/L - NOCA**

| Location ID | Location Name | ANC (μeq/L) |
|---|---|---|
| NOCA0010 | Doubtful Lake | 46.6 |
| NOCA0011 | Hidden Lake | 40.7 |
| NOCA0070 | Razorhone Creek Tributary, Point H | 40.0 |
| NOCA0080 | Tapto Lakes (east) | 14.3 |

| | | |
|---|---|---|
| NOCA0082 | Silver Lake | 35.6 |

Figure 7-3 contains a graph of the frequency distribution of mean ANC values in North Cascades National Park.

*Minimum ANC*

Of the 21 sampling locations which contained data for ANC calculations, 29% of them had minimum ANCs below 50 μeq/L. These locations are listed in Table 7-4.

**Table 7-4: Locations with minimum ANCs below 50 μeq/L - NOCA**

| Location ID | Location Name | ANC (μeq/L) |
|---|---|---|
| NOCA0010 | Doubtful Lake | 46.6 |
| NOCA0011 | Hidden Lake | 40.7 |
| NOCA0070 | Razorhone Creek Tributary, Point H | 40.0 |
| NOCA0075 | Galena Creek near Glacier, WA | 20.0 |
| NOCA0080 | Tapto Lakes (east) | 14.3 |
| NOCA0082 | Silver Lake | 35.6 |

The mean and minimum values are, for many sites (62%), the same because sampling was conducted only one time. Another 14% of sites were based on 5 or fewer samples; each of these sites has a mean ANC value that is quite different than the minimum value. Figure 7-4 contains a graph of the frequency distribution of minimum ANC values in North Cascades National Park.

**Figure 7-3: Frequency Distribution of Mean ANC Values - NOCA**

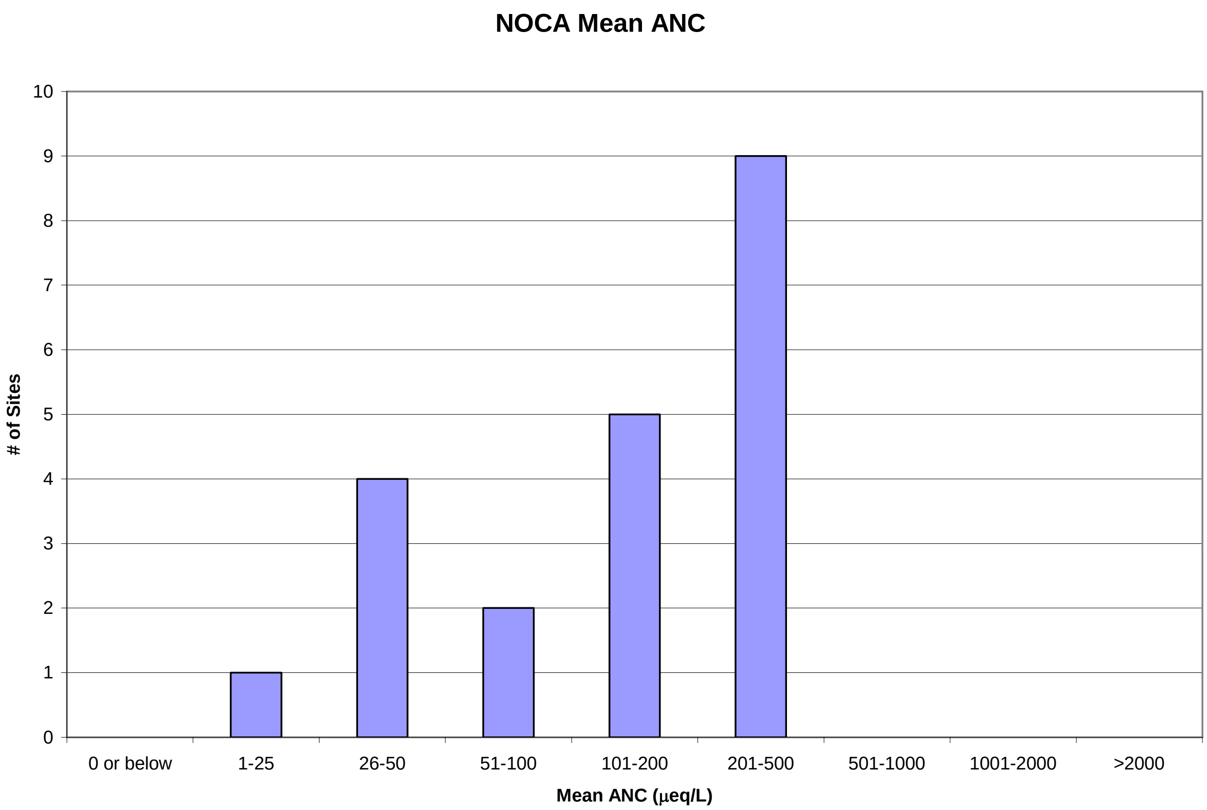
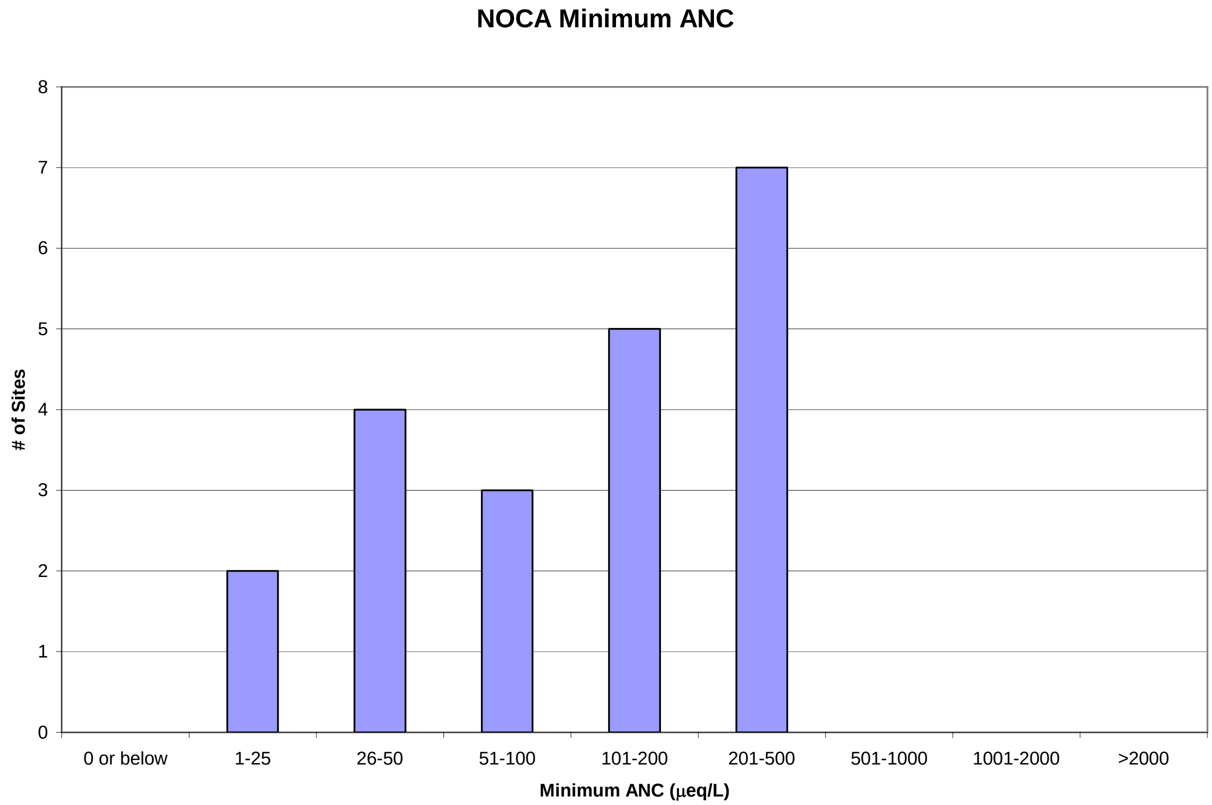


**Figure 7-4: Frequency Distribution of Minimum ANC Values - NOCA**




## Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

### *Lakes - Average Water Chemistry Values*

Table 7-5 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in North Cascades National Park and Figure 7-5 includes graphical representations of this data.

Three of the lake sites had only one data parameter for the DSS (nitrate concentration). The DSS makes no suggestions for any of the categories for these lakes except for ‘Disturbance or Land Use Impacted’.

**Table 7-5: DSS Results for Average Lake Values - NOCA**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 12 | 13 | 0 | 14 | 4 | 17 | 12 |
| -0.59 to -0.20 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| -0.19 to 0.20 | 3 | 3 | 17 | 3 | 4 | 0 | 2 |
| 0.21 to 0.60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.60 to 1.00 | *1 | *1 | 0 | 0 | 9 | 0 | 3 |

* Hidden Lake

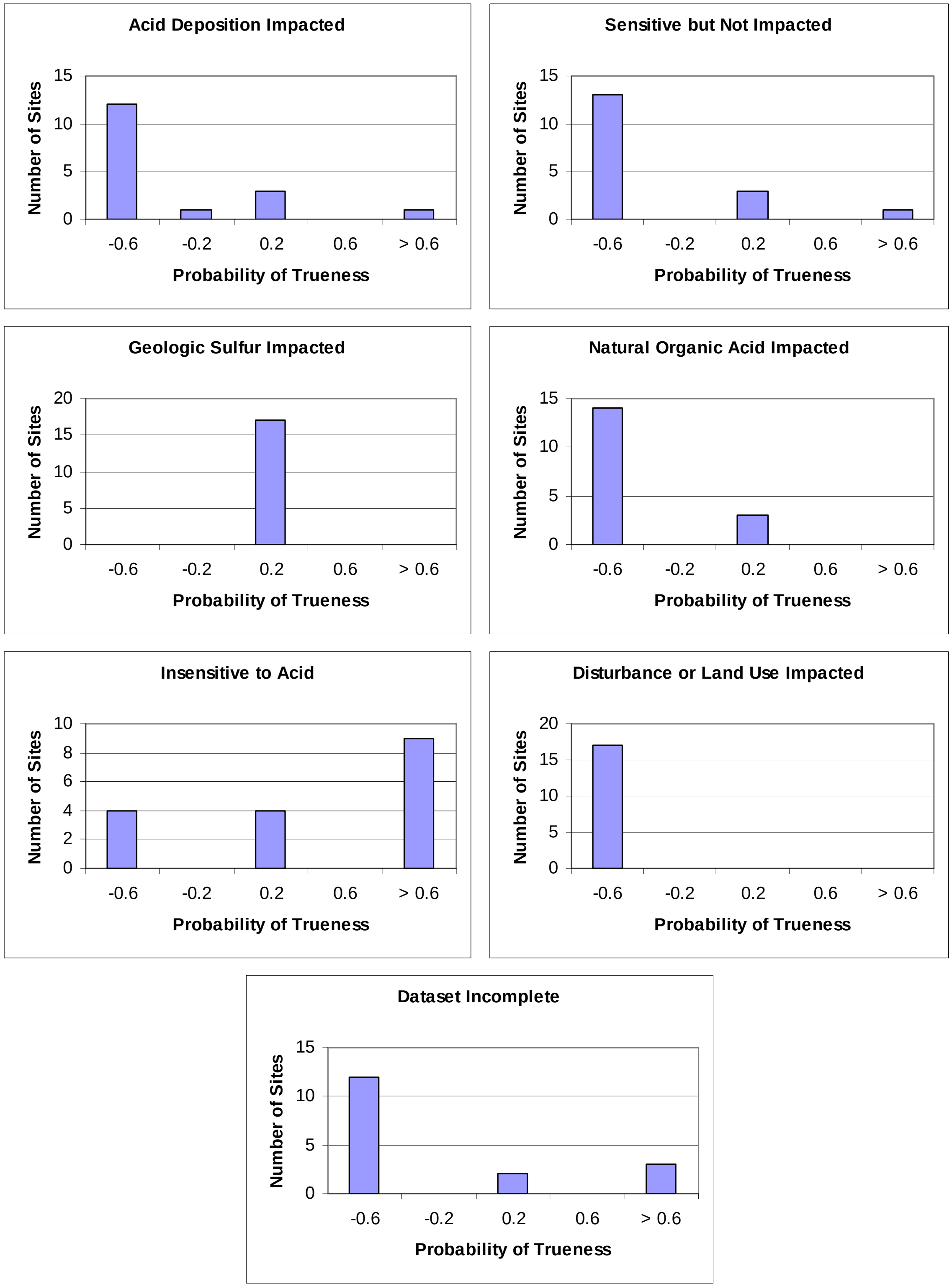
Of the 14 lakes for which the DSS made an assessment about acid deposition, 13 are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category), 12 with a high degree of certainty. These lakes have high ANC and pH values, low nitrate concentrations, and relatively low sulfate concentrations. The lake identified as acid deposition impacted (true in the 'Acid Deposition Impacted category'), Hidden Lake, has an extremely low specific conductance (5 μmhos/cm) in addition to a low ANC (41 μeq/L) and few base cations (26 μeq/L). Low specific conductance suggests that the lake may already have been impacted by acid deposition (Sullivan et al., in review).

The same 13 lakes are also classified as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These lakes have high ANC values, low nitrate concentrations, and relatively low sulfate concentrations compared to relatively high base cation concentrations. Hidden Lake, with low buffering capacity, as mentioned above was found to be a sensitive but not impacted lake (true in the 'Sensitive but Unimpacted' category).

It seems counterintuitive that a single water body can be both 'Acid Deposition Impacted' and 'Sensitive but not Impacted'. There is a reasonable interpretation of these seemingly conflicting categories. The Hidden Lake results demonstrate that the model allows for some uncertainty in definitely lumping a lake into one category at the exclusion of all others. The potential for it to be sensitive but unimpacted is due to the fact that there still is fairly high ANC and pH; impact, if it exists, would be gauged to be moderate. The potential for it to be acid deposition impacted is due to nitrate and sulfate values that could well be caused by acid deposition and to ANC that is low enough to have suffered some moderate impact.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

**Figure 7-5: Charts of Synthesis Results for Average Lake Values - NOCA**



All 14 lakes with data were found to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted" category). This is due to the low levels of DOC found in the samples (<1.6 mg/L) and the high ANC values (>100 μeq/L).

Nine lakes are insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (>100 μeq/L) and high specific conductance values (≥ 13 μmhos/cm). Four lakes were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category). These locations had ANC values below 50 μeq/L and conductance values under 10 μmhos/cm. The four sensitive lakes are Doubtful Lake (NOCA0010), Hidden Lake (NOCA0011), Tapto Lakes - East (NOCA0080), and Silver Lake (NOCA0082).

No lakes were found to suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). In all cases, the nitrate concentration was ≤ 5 μeq/L.

The DSS evaluates all of the locations in terms of the completeness of the input data. The twelve locations containing all seven inputs have complete datasets. Five of the locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

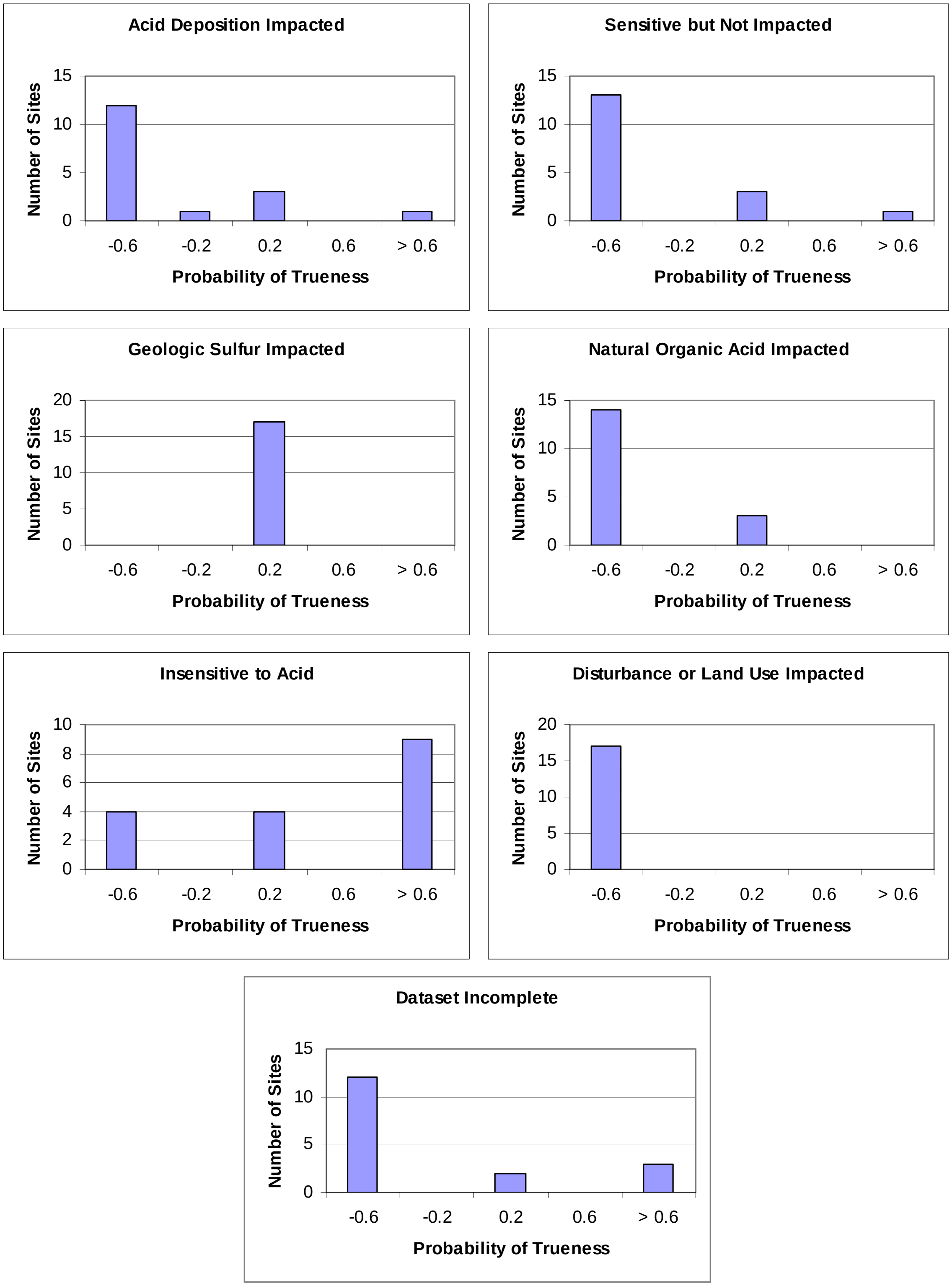
*Lakes – Extreme Water Chemistry Values*

Table 7-6 lists the results of the DSS for extreme values of water chemistry parameters in lakes in North Cascades National Park. Figure 7-6 graphically represents these results.

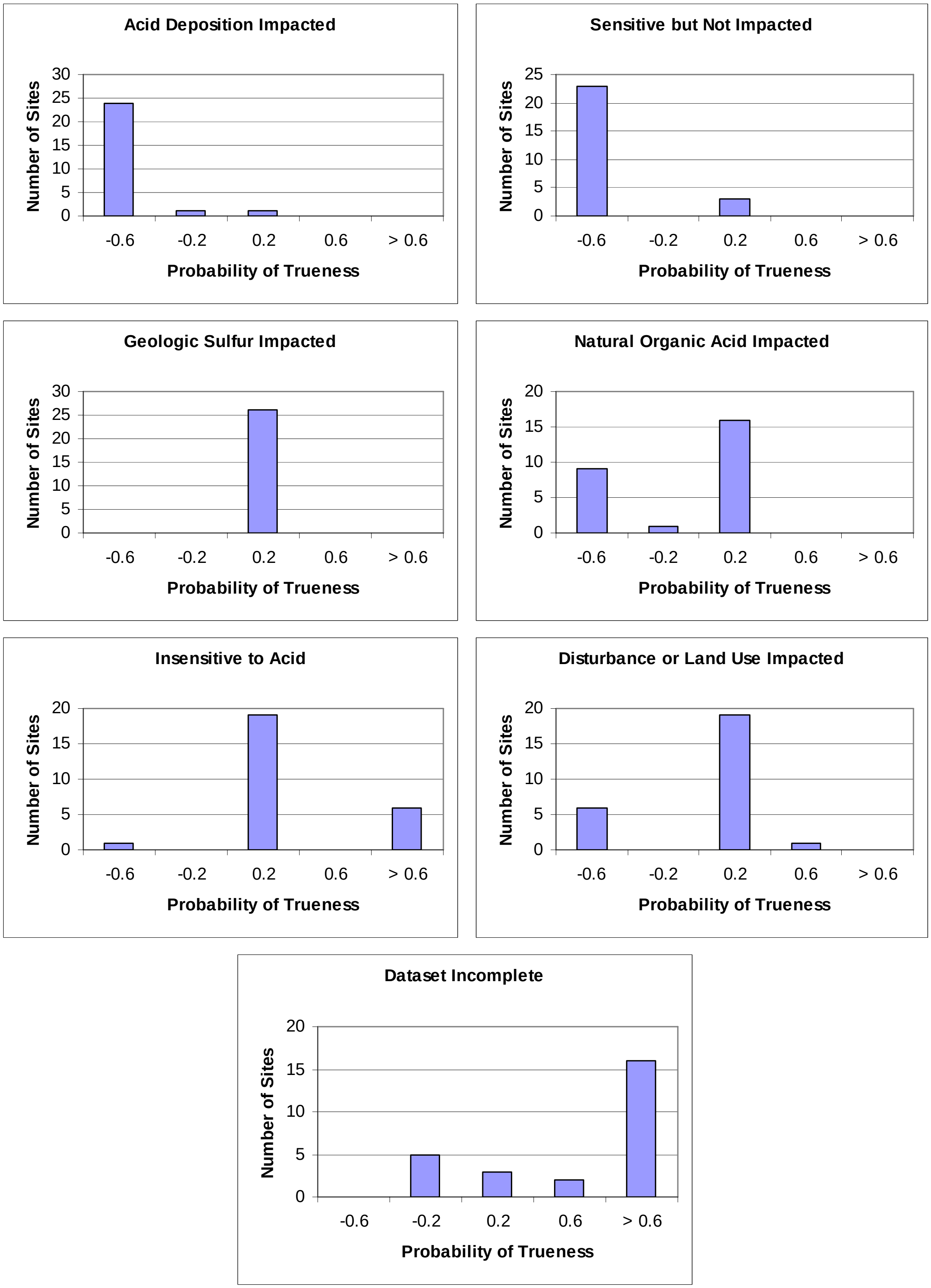
**Table 7-6: DSS Results for Extreme Lake Values - NOCA**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 12 | 13 | 0 | 14 | 4 | 17 | 12 |
| -0.59 to -0.20 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| -0.19 to 0.20 | 3 | 3 | 17 | 3 | 4 | 0 | 2 |
| 0.21 to 0.60 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0.60 to 1.00 | 1 | 1 | 0 | 0 | 9 | 0 | 3 |

**Figure 7-6: Charts of Synthesis Results for Extreme Lake Values - NOCA**



## Figure 7-7: Charts of Synthesis Results for Average Stream Values - NOCA



The DSS result distribution for extreme lake values are exactly the same as that for average lake values. This occurred for two reasons. First, results at 76% of the lake locations came from a single test at that location. Therefore, the mean value for a parameter and its minimum value are the same. Second, the lakes are sufficiently buffered such that the minimum ANC (>100 μeq/L) and specific conductance (>10 μmhos/cm) values and concentrations of base cations are still very high and the N (<7 μeq/L) and DOC (<2 mg/L) values are still very low.

*Streams - Average Water Chemistry Values*

Table 7-7 lists the results of the Synthesis DSS for average water chemistry values at streams in North Cascades National Park and Figure 7-7 represents this data graphically.

**Table 7-7: DSS Results for Average Stream Values - NOCA**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 24 | 23 | 0 | 9 | 1 | 6 | 0 |
| -0.59 to -0.20 | 1 | 0 | 0 | 1 | 0 | 0 | 5 |
| -0.19 to 0.20 | 1 | 3 | 26 | 16 | 19 | 19 | 3 |
| 0.21 to 0.60 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| 0.60 to 1.00 | 0 | 0 | 0 | 0 | 6 | 0 | 16 |

Thirteen of the stream sites had only one data parameter for the DSS. Twelve of these had only specific conductance; the DSS makes no recommendations for any of the categories for these streams except for 'Acid Deposition Impacted' and 'Sensitive but Unimpacted'. The other site had only a nitrate concentration. The DSS makes no recommendations for any of the categories for this stream except for 'Disturbance or Land Use Impacted'.

Of the 25 streams for which the DSS made an assessment, none were found to be impacted by acid deposition (false in the 'Acid Deposition Impacted' category). Seven of the streams have high ANC and pH values, high base cation concentrations, low nitrate concentrations, and relatively low sulfate concentrations. The DSS based the evaluation of one stream upon its high concentration of base cations. Twelve streams had only a high specific conductance, while 5 others combined this factor with a high pH to achieve this rating.

Twenty-three streams are rated false in the 'Sensitive but Unimpaired' category. These streams have high ANC and specific conductance values, low nitrate concentrations, or relatively low sulfate concentrations compared to relatively high base cation concentrations. Thus, the streams rate as false for this category because they are insensitive to acid deposition rather than because they are impacted by acid deposition. Two streams that had a pH slightly below 7 (~6.9) and relatively low specific conductance levels (<20 μmhos/cm), were deemed not to have enough information for the DSS to make a decision with any level of certainty.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

Nine streams do not have evidence that high dissolved organic carbon appreciably contributed to low ANC or pH (false in the 'Natural Organic Acid Impacted' category). Characteristics of eight of these streams include high ANC, specific conductance, and pH values, a high concentration of base cations, and low concentrations of sulfate and nitrate. The remaining site has the highest pH of any of the streams (7.36) and has a high specific conductance value (44 μmhos/cm). For the 19 streams for which no assessment was made, the DSS could not classify the DOC concentration as 'high'.

Six streams are insensitive to acid deposition (true in the 'Insensitive to Acid' category). Indicative of these results are high ANC values (>80 μeq/L) and high specific conductance values (≥ 22.5 μmhos/cm). These streams are Park Creek near Concrete, WA (NOCA0051), Swift Creek near Concrete, WA (NOCA0052), Baker River above Blum Creek near Concrete, WA (NOCA0057), Galena Creek, Point A (NOCA0069), Galena Creek near Glacier, WA (NOCA0075), and Bagley Creek, Point D (NOCA0076). Most of the streams did not have enough data for the DSS to make a meaningful decision concerning its sensitivity. One stream, Razorhone Creek Tributary, Point H (NOCA0070), was found to be sensitive to further acidic deposition (false 'Insensitive to Acid' category). It had an ANC value of 40 μeq/L and the lowest conductance value of any stream, 14 μmhos/cm.

The DSS reports six streams as not impacted due to disturbance or land use purposes (false in the 'Disturbance or Land Use Impacted' category. In all cases, the nitrate concentration was ≤ 6 μeq/L. Two sites with nitrate concentrations above 10 μeq/L had positive values for this category from the DSS. The nitrate level of Baker River above Blum Creek near Concrete, WA (NOCA0057), 11 μeq/L, was not high enough for the DSS to give this location any certainty concerning this category. The other site, Galena Creek, Point A (NOCA0069), had a nitrate concentration of 12 μeq/L. The DSS was fairly confident that the impacts found at this location came from anthropogenic nitrogen inputs (true in the 'Disturbance or Land Use Impacted' category.

The DSS evaluates all of the locations in terms of the completeness of the input data. The six sites with six inputs are reasonably certain to have complete datasets. The other 21 locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Streams - Extreme Water Chemistry Values*

Table 7-8 contains the results of the Synthesis DSS of extreme water chemistry value for streams in North Cascades National Park. Figure 7-8 includes graphs of the data in this table.

**Table 7-8: DSS Results for Extreme Stream Values - NOCA**

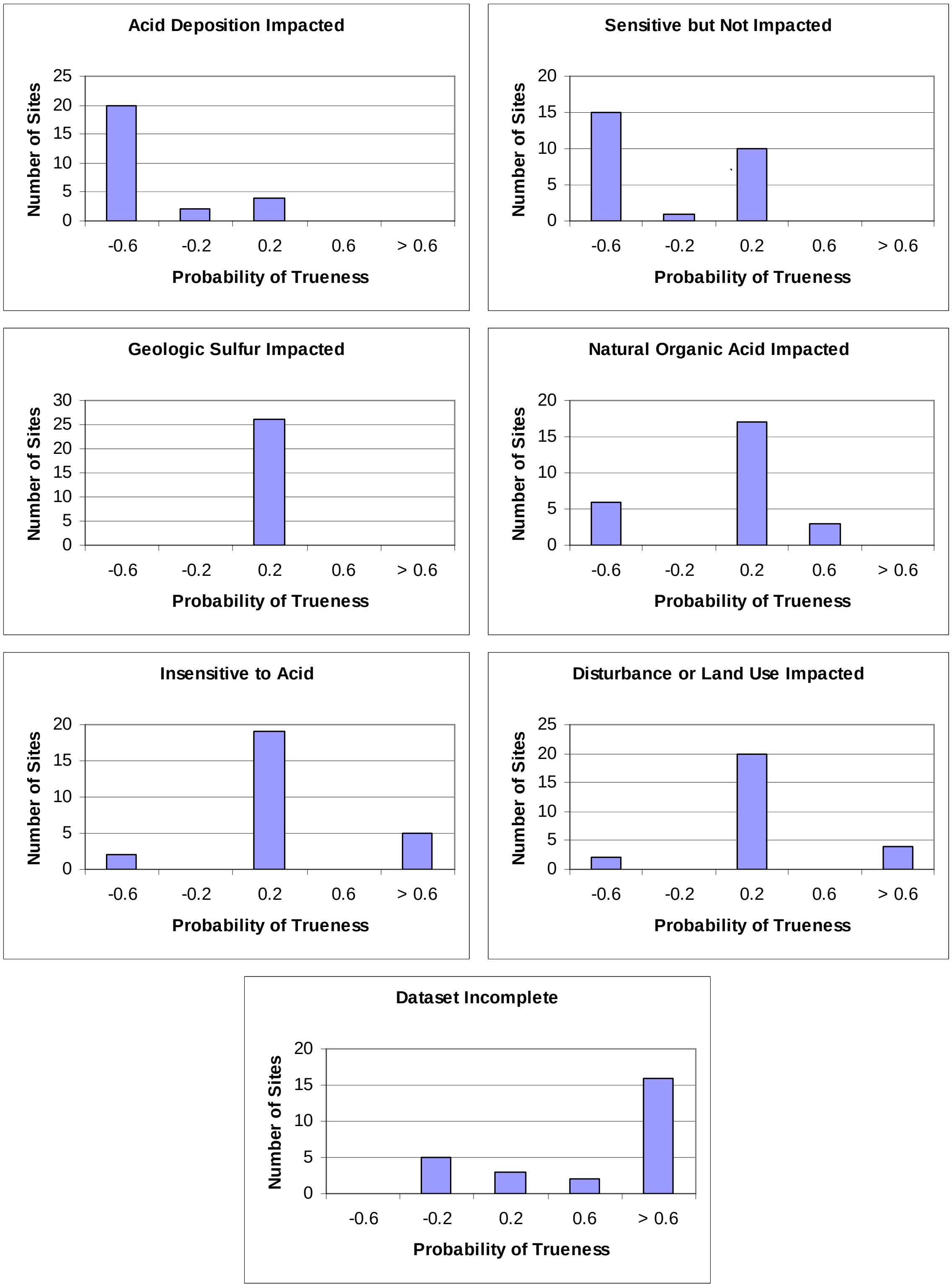
| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 20 | 15 | 0 | 6 | 2 | 2 | 0 |
| -0.59 to -0.20 | 2 | 1 | 0 | 0 | 0 | 0 | 5 |
| -0.19 to 0.20 | 4 | 10 | 26 | 17 | 19 | 20 | 3 |
| 0.21 to 0.60 | 0 | 0 | 0 | 3 | 0 | 0 | 2 |
| 0.60 to 1.00 | 0 | 0 | 0 | 0 | 5 | 4 | 16 |

Of the 22 streams which the DSS assessed concerning acid deposition impact, all were found to have not been impacted by acid deposition (false in the 'Acid Deposition Impacted' category). Seven of the streams have high ANC and pH values, high base cation concentrations, low nitrate concentrations, and relatively low sulfate concentrations. The evaluation of one stream comes from its high concentration of base cations. Nine streams had only a high specific conductance, while three others combined this factor with a high pH to achieve this rating. The two that are false with a reasonable degree of certainty use only specific conductance data. At three streams, specific conductance values drop to around 10 μmhos/cm and pH dropped below 6 at two of the three. This was enough to cause the DSS to make no recommendation concerning this category with respect to these sites.

Only fifteen of these streams were found to be insensitive to acid (false in the 'Sensitive but Not Impacted' category). For those stream sites that had minimum specific conductance levels (≤ 20 μmhos/cm) and no other data for the DSS to utilize, the DSS made no recommendation.

Three streams were found to be impacted by natural organic levels (true in the 'Natural Organic Acid Impacted' category): Baker River above Blum Creek near Concrete, WA (NOCA0057), Galena Creek, Point B (NOCA0071), and Bagley Creek, Point E (NOCA0077). This means that high DOC levels exist, reducing pH or ANC levels. At each stream, pH, specific conductance, and base cation concentrations were low. The same is true of Galena Creek, Point A (NOCA0069), which shifted from being almost certainly false in this category to uncertain.

**Figure 7-8: Charts of Synthesis Results for Extreme Stream Values - NOCA**



Galena Creek near Glacier, WA (NOCA0075) moved from being true with regard to the 'Insensitive to Acid' category to being false. This means given its most extreme values, this stream is sensitive to acid, where it was not sensitive to acid given its mean values. This stream's minimum ANC was one-fourth of its average ANC and its minimum specific conductance level was 25% lower than the average level. It joins the stream found to be false, meaning it is sensitive to acid, at average levels, Razorhone Creek Tributary, Point H (NOCA0070).

The DSS changed the classification of six streams with regards to the 'Disturbance or Land Use Impacted' category. Two sites, Park Creek near Concrete, WA (NOCA0051), Swift Creek near Concrete, WA (NOCA0052), moved from being false, or not impacted by land use, to being uncertain. Their maximum nitrate levels were double their average values. Two locations along the Skagit River at Newhalem, WA (NOCA0028 and NOCA0029) moved from being false, or unimpacted, to being true, or impacted. Their average nitrate concentrations were 6 μeq/L. In contrast, the maximum value at these two points was 86 μeq/L. The nitrate level of Baker River above Blum Creek near Concrete, WA (NOCA0057), changed from 11 μeq/L to 17 μeq/L. The DSS changed this streams' classification with regards to the 'Disturbance or Land Use Impacted' category from uncertain to true.

## Analysis

In agreement with the regional NPS report (Eilers et al. 1994), based on available data, the majority of waters of North Cascades NP appear unaffected by acid deposition. These waters have both low levels of acidic components and adequate buffering capacity (70% of locations with ANC data were >100 μeq/L). Whether these results are representative for the entire park is questionable as only half of locations with data in the Horizon report had ANC measurements and very few waters even were reported. In addition, as noted above, the data is not current, representing conditions at least more than 10 years ago and up to 32 years ago. Also, data for many of the more sensitive waters in NOCA are not available. Data from the regional report mention the existence of some low-alkalinity (less than 10 μeq/L) waters in the park, but do not specify which waters. None of the waters listed in the Horizon report have ANC values below 14 μeq/L. Lake Ann clearly represents an extreme of watershed sensitivity (Brakke 1984); its data are not listed in the Horizon report.

The main acidic components analyzed by the DSS are the ones that occur most often in air pollution, nitrate and sulfate. The average level of nitrate across these waters is very low. Of the 25 locations that have nitrate data, 23 of them are at levels below 6 μeq/L and 11 sites, all lakes, have levels below 2 μeq/L. For each of the years 1990, 1991, and 1992, the nitrate level in wet deposition was 1.6 μeq/L. The average nitrate level in the waters of NOCA is reasonable given the level of nitrate in wet deposition.

Of the 20 locations with sulfate data, 17 of them are at levels above 30 μeq/L. Sulfate levels in wet deposition averaged 5.1 μeq/L between 1990 and 1992. To reach these average sulfate levels, the rate of evapotranspiration would have to be extraordinarily high or a large portion of the sulfate must come from a geologic source.

While only 28% of sampled locations measured dissolved organic carbon, these levels are extremely low when they are available. The highest recorded value of DOC is 1.6 mg/L, a value typical of oligotrophic waters. Typically, high-elevation waters, as those found in NOCA, contain lower carbon levels than those at lower elevations due to the historic lack of nutrients and extreme conditions in these areas.

A body of water that has an ANC of below 50 μeq/L is at risk of impact from exposure to acid. Six of the 21 water bodies had ANC values that met this criterion. These locations are listed in Table 7-9:

**Table 7-9: NOCA Water Bodies with minimum ANC <50 μeq/L**

| Location ID | Location Name | Sample Type | Impact(s) | # Obs | Last Sampled |
|---|---|---|---|---|---|
| NOCA0010 | Doubtful Lake | Lake | Sensitive to Acid | 1 | 1985 |
| NOCA0011 | Hidden Lake | Lake | Acid Deposition Impacted, Sensitive but Not Impacted | 1 | 1985 |
| NOCA0070 | Razorhone Creek Tributary, Point H | Stream | Sensitive to Acid | 1 | 1976 |
| NOCA0075 | Galena Creek near Glacier, WA | Stream | Sensitive to Acid | 2 | 1972 |
| NOCA0080 | Tapto Lakes (east) | Lake | Sensitive to Acid | 1 | 1985 |
| NOCA0082 | Silver Lake | Lake | Sensitive to Acid | 1 | 1985 |

*"Last Sampled" refers to the last documented sample from the Horizon Report used in this analysis.

To reiterate, since many of the lake locations had only one sample result listed in the Horizon reports, the results from the DSS with average and extreme water chemistry values for lakes were the same.

The six waters in Table 13 are of top priority for additional water sampling. Hidden Lake (NOCA0011) requires particular attention because the DSS found it to either be sensitive, but not yet impacted, or to have crossed the line to being impacted by acid deposition. Hidden Lake has a low ANC (41 μeq/L) and few base cations (26 μeq/L), and is subject to acidification at even low levels of acid inputs.

It is important to note that at those sites where mean and extreme values are not the same, chemistry based on the extreme data is unlikely to be found in nature. Such low values of specific conductance as shown at Razorhone and Tapto could not co-exist with such large concentrations of sulfate. To some extent, these incompatible combinations may impact the probabilities assigned to categories such as 'Geologic Sulfur Impacted'.

In addition to Hidden Lake, three lakes are sensitive to acid. The all had ANC values below 50 μeq/L and conductance values under 10 μmhos/cm. They are Doubtful Lake (NOCA0010), Tapto Lakes - East (NOCA0080), and Silver Lake (NOCA0082). Considering mean water chemistry values one stream, Razorhone Creek Tributary, Point H (NOCA0070), was also sensitive to acid. It had an ANC value of 40 μeq/L and the lowest conductance value of any stream, 14 μmhos/cm.

Table 7-10 shows eight streams that suggest sensitivity to future acid deposition based on extreme stream values.

**Table 7-10: Potentially Sensitive NOCA Streams Based on Extreme Water Chemistry Values**

| Location ID | Location Name | Impact(s)* | # Obs | Last Sample |
|---|---|---|---|---|
| NOCA0028 | Skagit River at Newhalem, WA | Disturbance/Land Use Impacted | 0 | 1977 |
| NOCA0029 | Skagit River at Newhalem, WA | Disturbance/Land Use Impacted | 0 | 1977 |
| NOCA0057 | Baker River above Blum Creek near Concrete, WA | Natural Organic Acid Impacted, Disturbance/Land Use Impacted | 4 | 1977 |
| NOCA0069 | Galena Creek, Point A | Disturbance/Land Use Impacted | 17 | 1976 |
| NOCA0070 | Razorhone Creek Tributary, Point H | Sensitive to Acid | 1 | 1976 |
| NOCA0071 | Galena Creek, Point B | Natural Organic Acid Impacted | 0 | 1975 |
| NOCA0075 | Galena Creek near Glacier, WA | Sensitive to Acid | 2 | 1972 |
| NOCA0077 | Bagley Creek, Point E | Natural Organic Acid Impacted | 0 | 1976 |

At those locations that were impacted by disturbance or land use (true in the 'Disturbance/Land Use Impacted' category), relatively high extreme nitrate concentrations exist. Extreme nitrate concentrations at the two locations along the Skagit River at Newhalem, WA (NOCA0028 and NOCA0029) were 86 μeq/L; at Galena Creek, Point A (NOCA0069), the extreme nitrate level was 34 μeq/L; and at Baker River above Blum Creek near Concrete, WA (NOCA0057), 17 μeq/L. Baker River also had relatively low extreme specific conductance (13 μmhos/cm) and base cation values (108 μeq/L).

At the locations that had high DOC levels that impacted ANC or pH levels, Baker River, Galena Creek, Point B (NOCA0071), and Bagley Creek, Point E (NOCA0077), all had low specific conductance values (≤20 μmhos/cm). Bagley Creek had an extreme low pH of 2. However this value may be in error; if so, the classification by the DSS would also be in error.

Two streams were found to be sensitive to acid: Razorhone Creek Tributary, Point H (NOCA0070) and Galena Creek near Glacier, WA (NOCA0075). At Razorhone Creek, a low specific conductance level (6 μmhos/cm) is responsible, while at Galena Creek, it is the low minimum ANC value (20 μeq/L).

Given time, personnel, geographic, and financial resource limitations, it is important to prioritize potential and existing problem areas at specific bodies of water, to collect more samples at these locations, and to run a standardized set of chemical analyses against these samples.

The twelve water bodies listed below are locations where additional sampling should take place first. Among these waters, obtaining samples at Hidden Lake is a high priority, as it may already be impacted by acid deposition. It may be the most sensitive water body and deserves a close look.

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| NOCA0010 | Doubtful Lake | NOCA0070 | Razorhone Creek Tributary, Point H |
| NOCA0011 | Hidden Lake | NOCA0071 | Galena Creek, Point B |
| NOCA0028 | Skagit River at Newhalem, WA | NOCA0075 | Galena Creek near Glacier, WA |
| NOCA0029 | Skagit River at Newhalem, WA | NOCA0077 | Bagley Creek, Point E |
| NOCA0057 | Baker River above Blum Creek near Concrete, WA | NOCA0080 | Tapto Lakes (east) |
| NOCA0069 | Galena Creek, Point A | NOCA0082 | Silver Lake |

Whether to sample lakes or streams depends on the type of impact being looked for. In general, streams are more susceptible to episodic changes throughout the year, while lakes tend to show the effects of long-term, chronic changes. Both are important in making water quality management decisions.

For North Cascades NP, Doubtful Lake, Tapto Lakes – East, and Silver Lake were deemed by the DSS to not be insensitive to future acid additions, and should be monitored for changing conditions. For those streams that have been impacted by land use or disturbance, it is important to find out the time of year that the extreme high N conditions existed. As discussed above, this might be the result of snowmelt runoff, which preferentially washes N from the snowpack downstream in pulses. Such extreme values are not seen in these locations for the rest of the year.

The regional NPS report cited in earlier sections recommends analysis of 15 measurements for each water body sampled. With the exception of specific conductance, these measurements cover those needed to input complete data into the DSS for processing; this would yield more certain recommendations for more water bodies in a park.

The number of classifications that were returned with no certainty presents challenges in summarizing park surface water data. While only 3 of the 17 lakes were found to have an incomplete dataset with high certainty, 16 of the 26 streams returned this condition. The other classifications for these locations may be based on inadequate data. While some conclusions can be based on just a single piece of data, the lack of data left the DSS unable to report with any certainty with respect to the ‘Natural Organic Acid Impacted’, ‘Insensitive to Acid’, and ‘Disturbance or Land Use Impacted’ categories at most stream locations. Such a large degree of uncertainty makes it difficult to make an overall recommendation for the park concerning water quality management decisions.

The DSS did not make an assessment about any of the locations in the ‘Geologically Sulfur Impacted’ category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

It is difficult to know how applicable the classifications reported by the DSS for North Cascades NP are to the current state of the water bodies. None of the 43 sites that had any data collection were collected after 1990. At best, the data in this report is 15 years old and may not indicate current water chemistry conditions. It highlights the need for additional sampling to take place or be reported on so that the DSS can utilize current data for making recommendations.

In addition, it may be more important to sample sensitive area more frequently than to sample all water bodies, especially those deemed not to be susceptible to acid deposition. This would assist in determining if these water bodies are subject to episodic or chronic acidification.

## Conclusion

Pollution levels have substantially increased over the last 150 years. Sulfate and nitrate are the most important anionic components in acidic deposition. The air quality in the Pacific Northwest region is very good compared to other areas of the U.S. A regional NPS report showed that this region had low levels of S deposition (0.5 to 4 kg S/ha/yr) and N deposition (0.5 to 2.4 kg N ha/yr) during the early 1990s. However, emissions from areas outside the park, such as Seattle and Vancouver, British Columbia, have the potential to impact the park.

Pollution effects are of concern in this region because its lakes are likely among the most sensitive aquatic systems anywhere in the world. Acidic deposition of both S and N may cause chronic or episodic acidification of surface waters at low levels of deposition.

This evaluation focuses on North Cascades NP (NOCA). The water quality data was extracted from the Horizon report, completed in May 1995. Values for specific conductance, pH, ANC, DOC, nitrate, the sum of base cations, and sulfate were obtained. These reports may not contain data for the most sensitive water bodies; for example, the report contains only 7.8% of lakes in NOCA. Therefore, the analysis may not give a true representation of the sensitivity or level of impact by acid deposition for the entire park.

The regional NPS report for the Pacific Northwest found the waters of NOCA mainly unaffected by acid deposition. Most locations have nitrate levels below 6 μeq/L and sulfate levels below 75 μeq/L. Only one of the pH levels was below 6. The Aquatic Chemistry DSS, using the Horizon data, found only 6 of the 43 water bodies, to be sensitive, either due to acid deposition, high organic concentrations or by high nitrate concentration as a consequence of agricultural activities, forestry, or other land use. One lake, Hidden Lake showed indications of N and S deposition impact.

A body of water that has an ANC of below 50 μeq/L is at risk to impact from exposure to acid. Six of the 21 water bodies that had ANC values met this criterion: Doubtful Lake, Hidden Lake, Razorhone Creek Tributary, Point H, Galena Creek near Glacier, WA, Tapto Lakes (east), and Silver Lake. Hidden Lake (NOCA0011) requires particular attention because it is possibly acid deposition impacted or may be sensitive to future acid deposition but not yet impacted. Hidden Lake has a low ANC (41 μeq/L) and few base cations (26 μeq/L). These six waters, and Hidden Lake in particular, are of top priority for additional water sampling.

Six other streams suggest sensitivity to future acid deposition based on extreme stream values: Skagit River at Newhalem, WA, Skagit River at Newhalem, WA, Baker River above Blum Creek near Concrete, WA, Galena Creek, Point A , Galena Creek, Point B, and Bagley Creek, Point E. At those locations that have been impacted by disturbance or land use, high extreme nitrate concentrations exist. At other locations, pH, specific conductance, and base cation concentrations were low.

The DSS result distribution for extreme lake values are exactly the same as that for average lake values. Many results contain data from one or two samples. At NOCA, sampling occurred once at 62% of all waters with data, including 86% of lakes. In these cases, the result is 'extreme' values that are the same as the mean values. With so few samples, it is difficult to ascertain if the data assembled is representative of the water body in question.

Data issues that affected this analysis include a general lack of data, infrequent sampling, and old data. Only 52% of water bodies in the report contained data relevant to the DSS. In addition, 37% of sites with data had only one data element used by the DSS. This lack of data left the DSS unable to report with any certainty most stream locations with respect to being impacted by high organic levels, high nitrogen levels, likely due to anthropogenic causes, and not being sensitive to acid due to high buffering capabilities. Such a large degree of uncertainty makes it difficult to make an overall recommendation for the park concerning water quality management decisions.

Data representing present conditions are needed. 77% of NOCA waters were sampled before 1990, and 51% were sampled before 1980. The Horizon report is 10 years old. It is likely the condition of these waters has changed during this period.

While an overall recommendation for the park cannot be made, the DSS has identified a dozen bodies of water that may require attention. Given resource limitations, it is important to prioritize potential and already existing problem areas at specific bodies of water, to collect more samples at these locations, and to run a standardized set of chemical analyses against these samples. The six waters that had ANC values below 50 μeq/L top the priority list. The other six waters that were impacted under extreme water chemistry conditions should be monitored for changes.

# Chapter 8 - Olympic National Park

## Background

The information in this section was taken from the Status of Air Quality and Effects of Atmospheric Pollutants on Ecosystems in the Pacific Northwest Region of the National Park Service (Eilers et al. 1994). The complete report is available on the web at the following site:

http://www2.nrintra.nps.gov/ard/reviews/PacificNW%20Review/index.html

## Description

Olympic National Park is situated in the center of the Olympic Peninsula of Washington State. It was designated the Olympus Forest Reserve in 1897, the Olympus National Monument in 1909, and Olympic National Park in 1938. The original park size was 363,420 hectares; a 50-mile coastal strip was added to the park in 1953.

The Olympic Peninsula is comprised of a central core of the rugged Olympic Mountains surrounded by almost level lowlands. Glaciation has strongly influenced landforms. All main river valleys are broad and U-shaped, and all major peaks are ringed with cirques, many containing active glaciers. High precipitation levels have caused rapid downcutting by streams, resulting in many steep mountain slopes.

The seaward slopes of the Olympics receive more precipitation than any other place in the contiguous United States; between 300 and 400 cm of precipitation fall annually at the Hoh and Queets Valleys. East of the mountains in Sequim, in the rain shadow of the Olympic Mountains, annual rainfall declines to only 45 cm.

The dominant aquatic feature of the park is the 13 major rivers flowing from the Olympic Mountains in all directions. These are well buffered systems draining from sedimentary bedrock and glaciers with high silt loads. There are many high-elevation lakes, some of which have been sampled, and several large low-elevation lakes that have been studied in some detail.

## Deposition

Most of the emissions in counties adjacent to OLYM are relatively low. The primary emissions of concern for OLYM are on the east side of Puget Sound in King and Pierce counties and to the south in Lewis County. The air quality-related major local emissions sources in Port Angeles are monitored within the city of Port Angeles by WDOE and near park headquarters south of the city.

The NADP/NTN site at the Hoh Ranger Station, established in 1983, is a low-elevation site (173 m) and provides valuable information on relatively pristine precipitation entering the ecologically important temperate rainforest. The primary polluted air masses of concern, however, enter the park from the east and south. Although deposition data to the west suggest that the pollution threat is currently low to moderate, there is no information to currently assess the severity of these pollution sources.

Figure 8-1 shows that sulfate wet deposition has declined from a peak of approximately 8 kg/ha/yr in 1990 to about 4 kg/ha/yr in 2003. This is representative of a national decline in sulfate deposition levels since the passage of the Clean Air Act.

**Figure 8-1: Sulfate wet deposition at Hoh Ranger Station NADP site in Olympic NP**

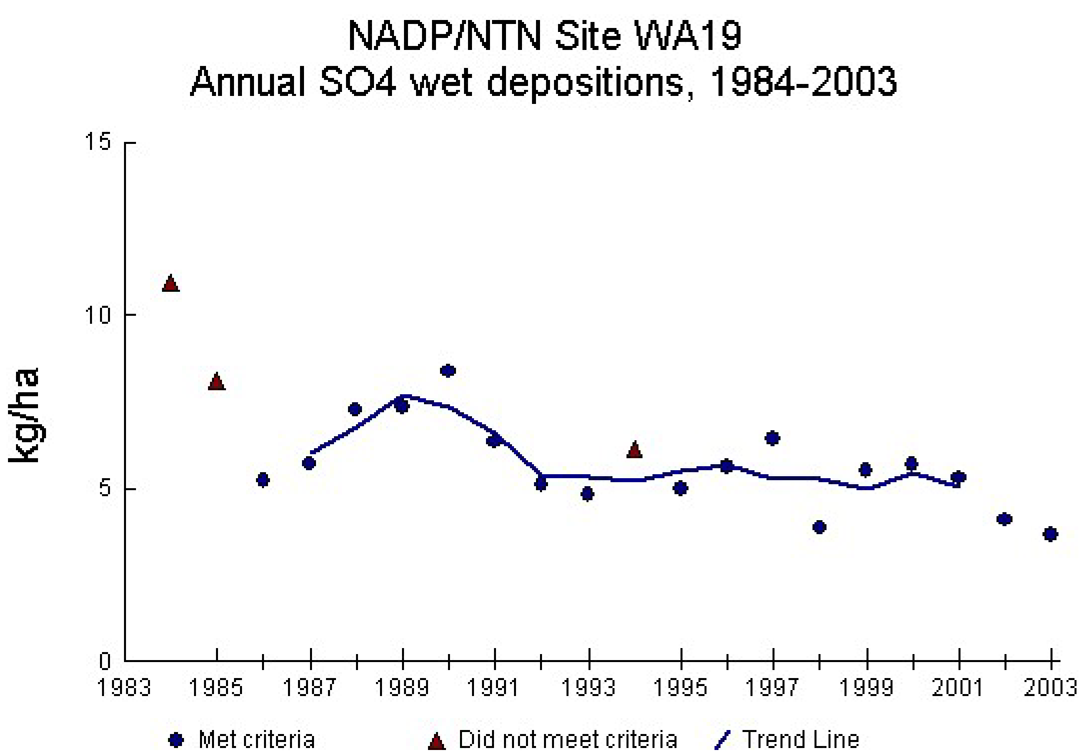
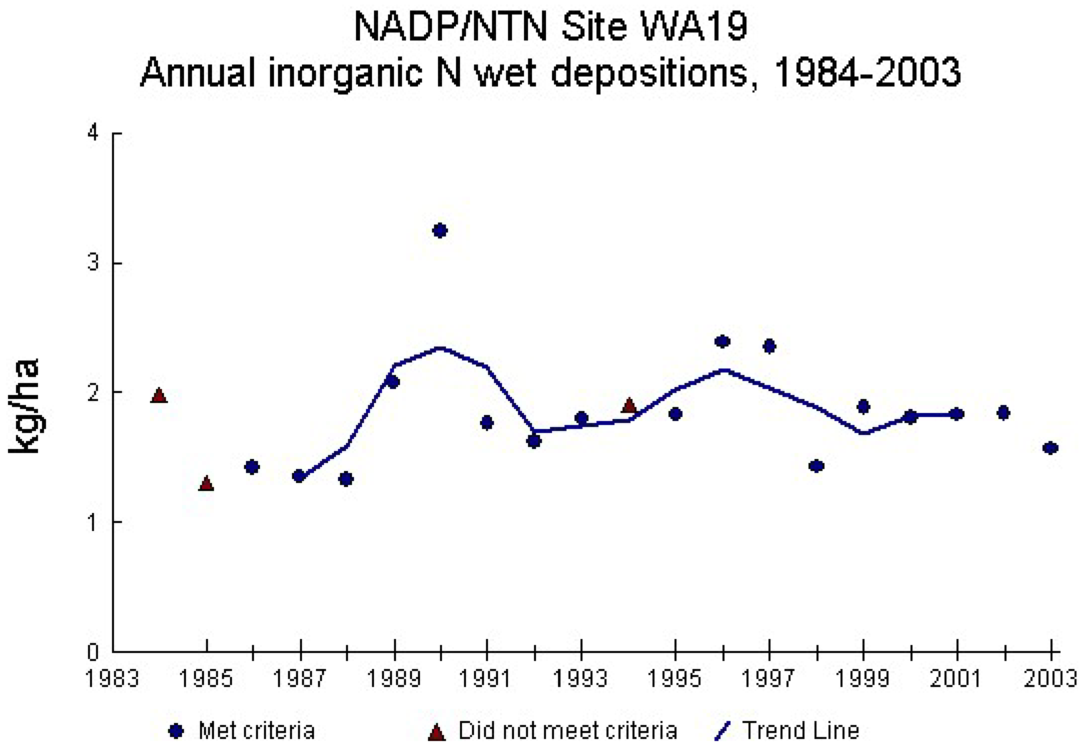



Figure 8-2 shows a slight long-term increase of inorganic nitrogen wet deposition since 1984, but no annual trends. The level of inorganic nitrogen deposition is low, fluctuating between 1-2 kg/ha/yr.

**Figure 8-2: Inorganic N wet deposition at Hoh Ranger Station NADP site in Olympic NP**




## Water Quality

Three lakes were sampled in the park as part of EPA's Western Lake Survey (Landers et al. 1987, Eilers et al. 1987). The lakes were moderate to high-alkalinity systems with extremely high $Na^+$, $Cl^-$, and $SO_4^{2-}$ from marine aerosols. Hoh Lake was sampled intermittently from 1985 to 1987 as part of the Hoh River Valley study (Edmonds et al. 1992). West Twin Creek in the Hoh Valley has been sampled weekly by using a stage-proportional sampler from 1984 to present (Edmonds et al. 1992).

Seven lakes were sampled in the OLYM as part of the Washington DOE High Alpine Lake sampling program from 1983-1985. One of the lakes had an ANC between 100-200 μeq/L, whereas the remaining lakes had ANC greater than 200 μeq/L. Nitrate concentrations averaged 5.5 μeq/L in the lakes.

Investigation of three lakes in the Seven Lakes Basin was conducted to evaluate the efforts of fish stocking on plankton. The three lakes had high ANC (181-438 μeq/L) and high $SO_4^{2-}$ (41-104 μeq/L); no $NO_3^-$ data were reported (Banks 1991).

Lake Crescent, the largest lake in the park, was the site of a non-point source assessment by the NPS (Boyle and Beeson 1991). They concluded that Lake Crescent was nitrogen-limited and there was little evidence for serious nutrient enrichment from anthropogenic watershed sources at this time.

The information on acid-base chemistry for lakes in the OLYM suggests that there are few systems with ANC less than 100 μeq/L; these are largely insensitive to stress from acidic deposition. This is expected given the sedimentary bedrock and the high rates of weathering associated with glacial meltwaters. The eastern portion of the park is potentially vulnerable to atmospheric pollution which receives deposition of pollutants from the Puget Sound area.

## Aquatic Chemistry Data and DSS Results

### Horizon Report

The Horizon report was released for Olympic NP in October 1999. The report contains information on 406 water bodies in the park. More water bodies exist, but were not sampled. 69% of water bodies in the report contained data relevant to the DSS. The report details 24 lakes, 207 streams, and 175 other waters in Olympic NP. Table 8-1 lists the number of sites that have data for each DSS component. The numbers indicate that data for both lake and stream sites are moderately complete.

**Table 8-1: Chemistry Component Summary - OLYM**

| | Total | Lakes | Streams | Others |
|---|---|---|---|---|
| Number | 406 | 24 | 207 | 175 |
| Conductance | 231 | 20 | 172 | 39 |
| pH | 186 | 20 | 114 | 52 |
| ANC | 68 | 8 | 58 | 2 |
| DOC | 13 | 4 | 9 | 0 |
| Nitrate | 211 | 12 | 178 | 21 |
| Base Cations | 104 | 5 | 96 | 3 |
| Sulfate | 107 | 4 | 96 | 7 |

Table 8-2 lists the number of locations that that contained a given number of elements used by the DSS. Two-thirds of lake sites and 47% of stream sites had two or fewer data elements used by the DSS. Only 21% of lake sites and 27% of stream locations had six of or all seven of the data elements required by the DSS. This indicates that a standard set of chemical analyses was not performed on many of water samples taken in the park.

**Table 8-2: Number of Elements Summary - OLYM**

| # of Elements | Total | Lakes | Streams | Others |
|---|---|---|---|---|
| 0 | 124 | 0 | 18 | 106 |
| 1 | 38 | 4 | 9 | 25 |
| 2 | 122 | 12 | 71 | 39 |
| 3 | 16 | 0 | 13 | 3 |
| 4 | 12 | 3 | 9 | 0 |
| 5 | 31 | 0 | 31 | 0 |
| 6 | 54 | 2 | 50 | 2 |
| 7 | 9 | 3 | 6 | 0 |

Of the 395 sites that had any data collection, including parameters not used by the DSS, 89 sites were last sampled in the 1960s, 213 in the 1970s, 26 in the 1980s, and 67 in the 1990s. The lake data, on average, was newer than the stream data, with 50% of lakes last sampled during the 1980s and 33% in the 1990s. In contrast, 59% of streams were last sampled in the 1970s, 5% in the 1980s, and 28% in the 1990s. Much of the data in this report is 15 years old or older and may not indicate current water chemistry conditions. It highlights the need for additional sampling to take place so that the DSS can have up to date data for making recommendations.

Of the 68 locations that had alkalinity data, sampling occurred only once at 38% of them. Alkalinity results were based on more than 10 samples at 25% of all locations. More frequent future sampling will aide in gaining a more robust data set for entry into the DSS.

## ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

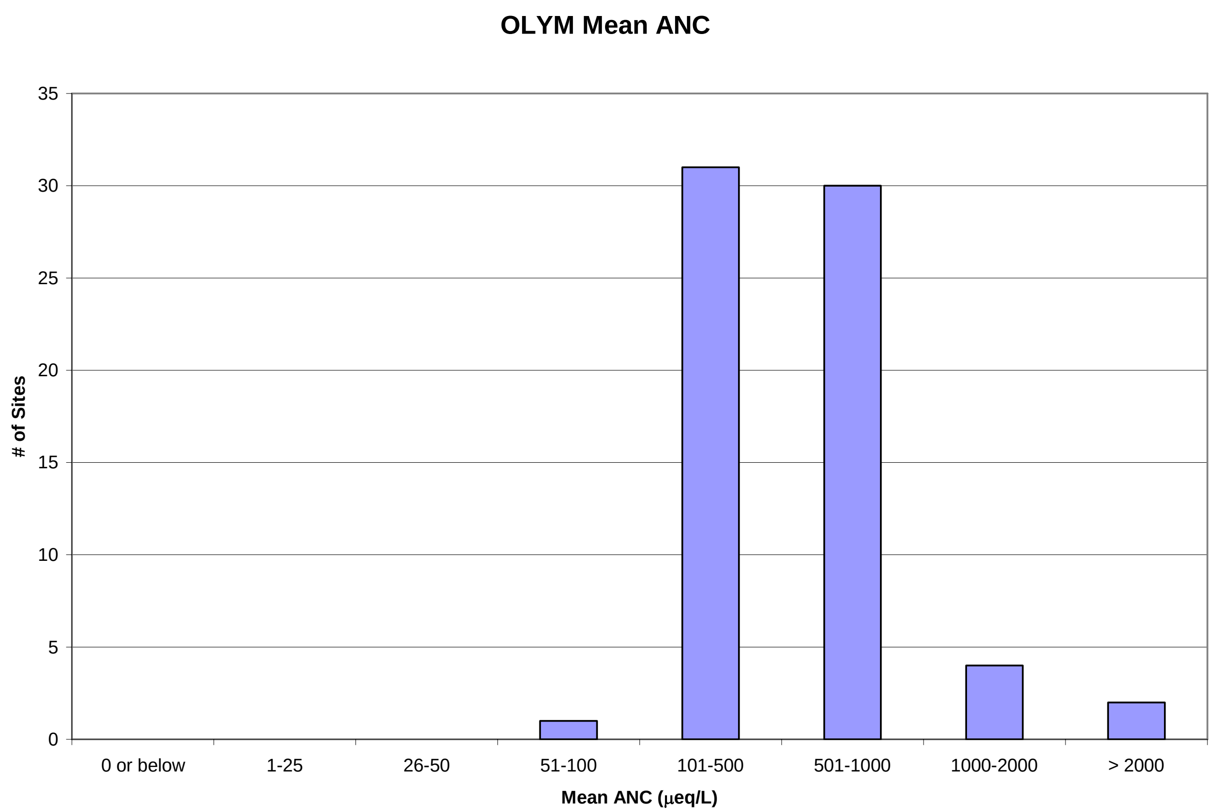
The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

### *Mean ANC*

Of the 68 sampling locations which contained data for ANC calculations, none had a mean ANC below 50 μeq/L and only 1 was below 100 μeq/L. This is consistent with the findings of other samples taken in the park as listed in the regional park report.

Figure 8-3 contains a graph of the frequency distribution of mean ANC values in Olympic NP.

**Figure 8-3: Frequency Distribution of Mean ANC Values - OLYM**

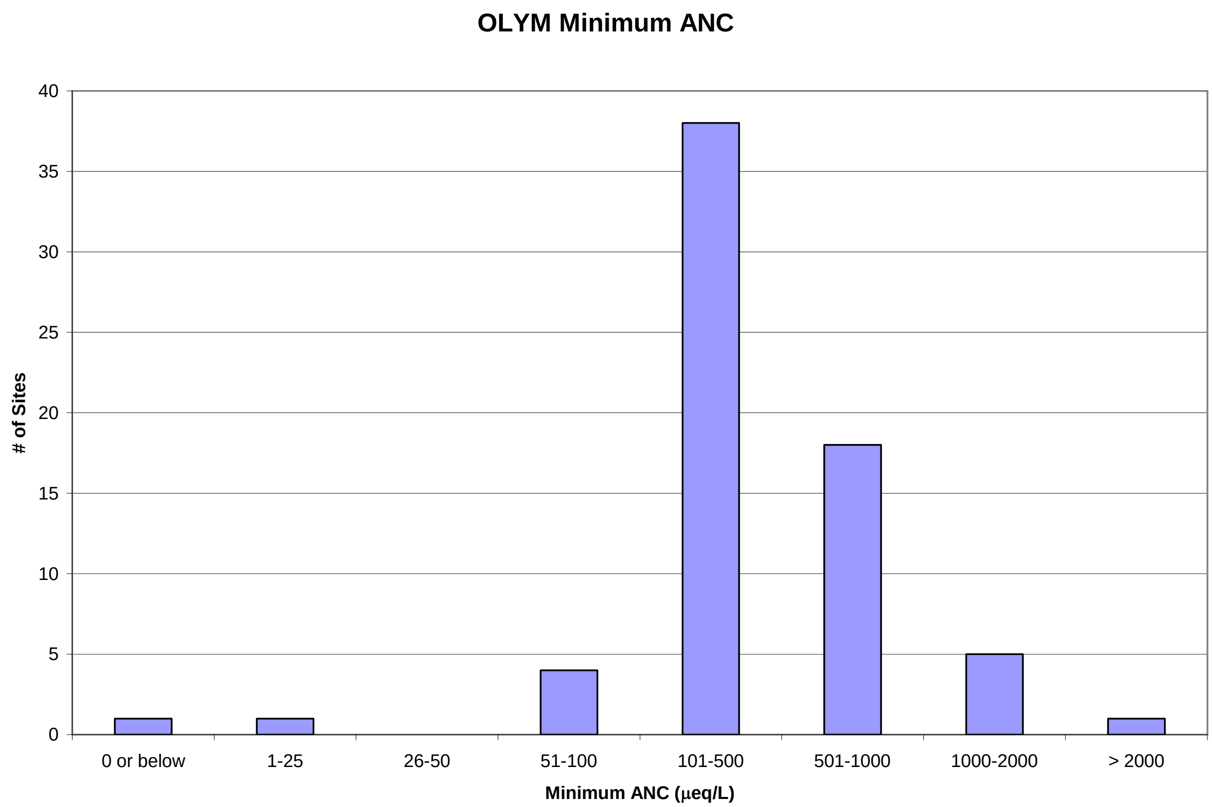



*Minimum ANC*

Of the 68 sampling locations which contained data for ANC calculations, two had mean ANCs below 50 μeq/L. These locations are OLYM0214, Quinault River at Quinault Lake, WA (20 μeq/L) and OLYM0258, Queets River near Clearwater, WA (0 μeq/L).

Figure 8-4 contains a graph of the frequency distribution of minimum ANC values in Olympic NP.

**Figure 8-4: Frequency Distribution of Minimum ANC Values - OLYM**




## Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

### *Lakes - Average Water Chemistry Values*

Table 8-3 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in Olympic NP and Figure 8-5 includes graphical representations of this data.

Four of the lake sites had only one data parameter for the DSS (nitrate concentration). The DSS makes recommendations with no certainty for all of the categories for these lakes except for Disturbance or Land Use Impacted.

**Table 8-3: DSS Results for Average Lake Values - OLYM**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 20 | 20 | 0 | 18 | 0 | 8 | 3 |
| -0.59 to -0.20 | 0 | 0 | 0 | 1 | 0 | 0 | 2 |
| -0.19 to 0.20 | 4 | 4 | 24 | 4 | 16 | 13 | 3 |
| 0.21 to 0.60 | 0 | 0 | 0 | 1 | 0 | 3 | 0 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 8 | 0 | 16 |

Of the 24 lakes for which the DSS made an assessment about acid deposition, 20 are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category). These lakes have high ANC (>100 μeq/L), conductance (> 30 μS/cm), and pH (> 7) values. None of the lakes were identified as being acid deposition impacted (true in the 'Acid Deposition Impacted' category.

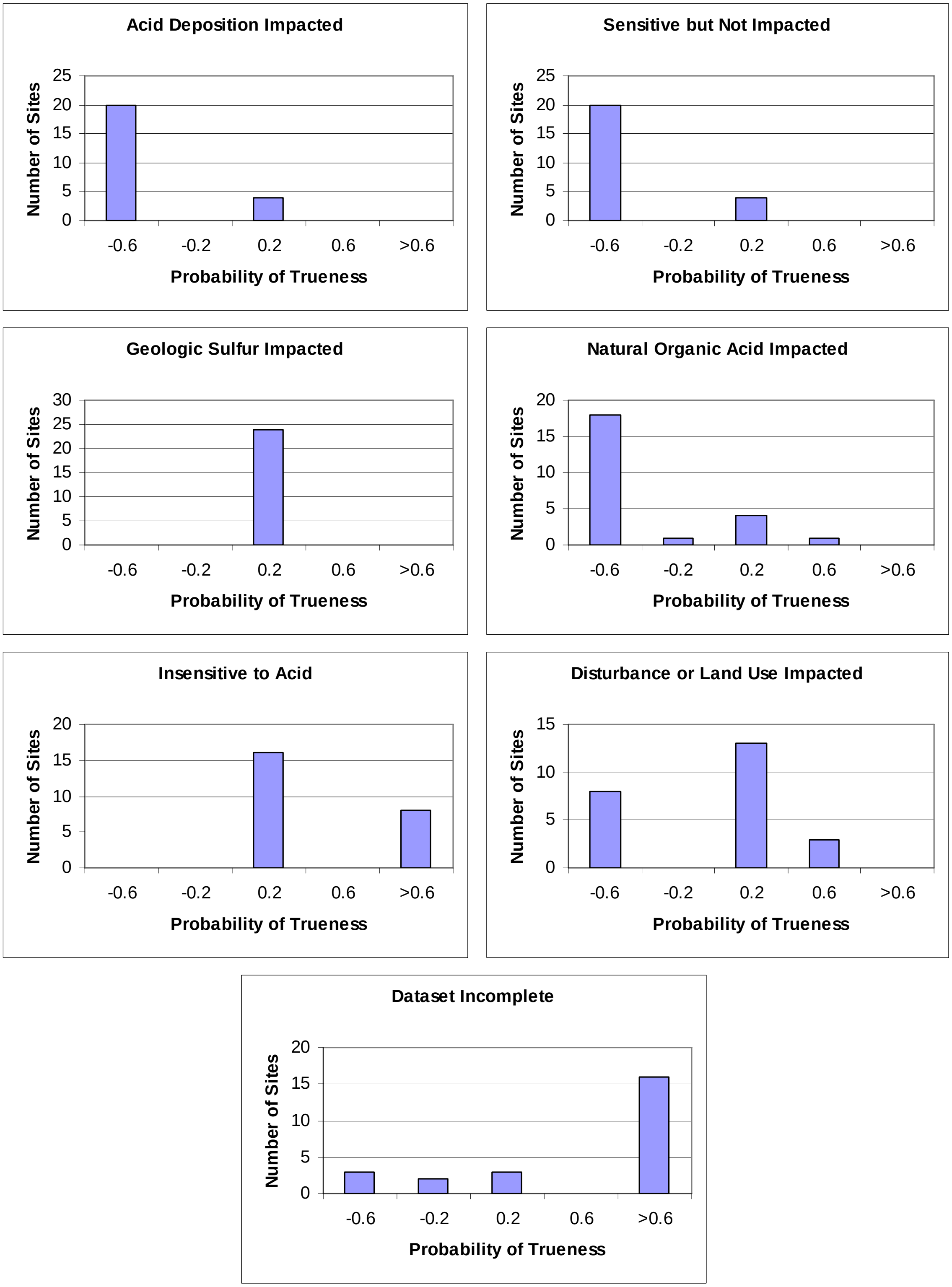
The same 20 lakes are also classified as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These lakes have high ANC and specific conductance values, and high base cation concentrations (≥ 175 μeq/L). No lakes were found to be sensitive but not impacted (true in the 'Sensitive but Unimpacted' category).

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

Nineteen lakes were found to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted' category). This is due to high buffer capacity as represented by high ANC values, high specific conductance values, and high concentrations of base cations. One lake, Ozette Lake (OLYM0386), was found to be impacted by natural organic acids (true in the 'Natural Organic Acid Impacted' Category). This location has the lowest ANC value (100 μeq/L) of any lake.

Eight lakes are insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (>100 μeq/L) and high specific conductance values (≥ 30 μmhos/cm). No lakes were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category). The DSS did not make an assessment for 16 lakes. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

**Figure 8-5: Charts of DSS Results for Average Lake Values - OLYM**



No lakes were found to suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). In all of these cases, the nitrate concentration was ≤ 5 μeq/L.

The DSS evaluates all of the locations in terms of the completeness of the input data. The 5 locations containing six or all seven inputs have complete datasets. Nineteen of the locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Lakes – Extreme Water Chemistry Values*

Table 8-4 lists the results of the DSS for extreme values of water chemistry parameters in lakes in North Cascades National Park. Figure 8-6 graphically represents these results.

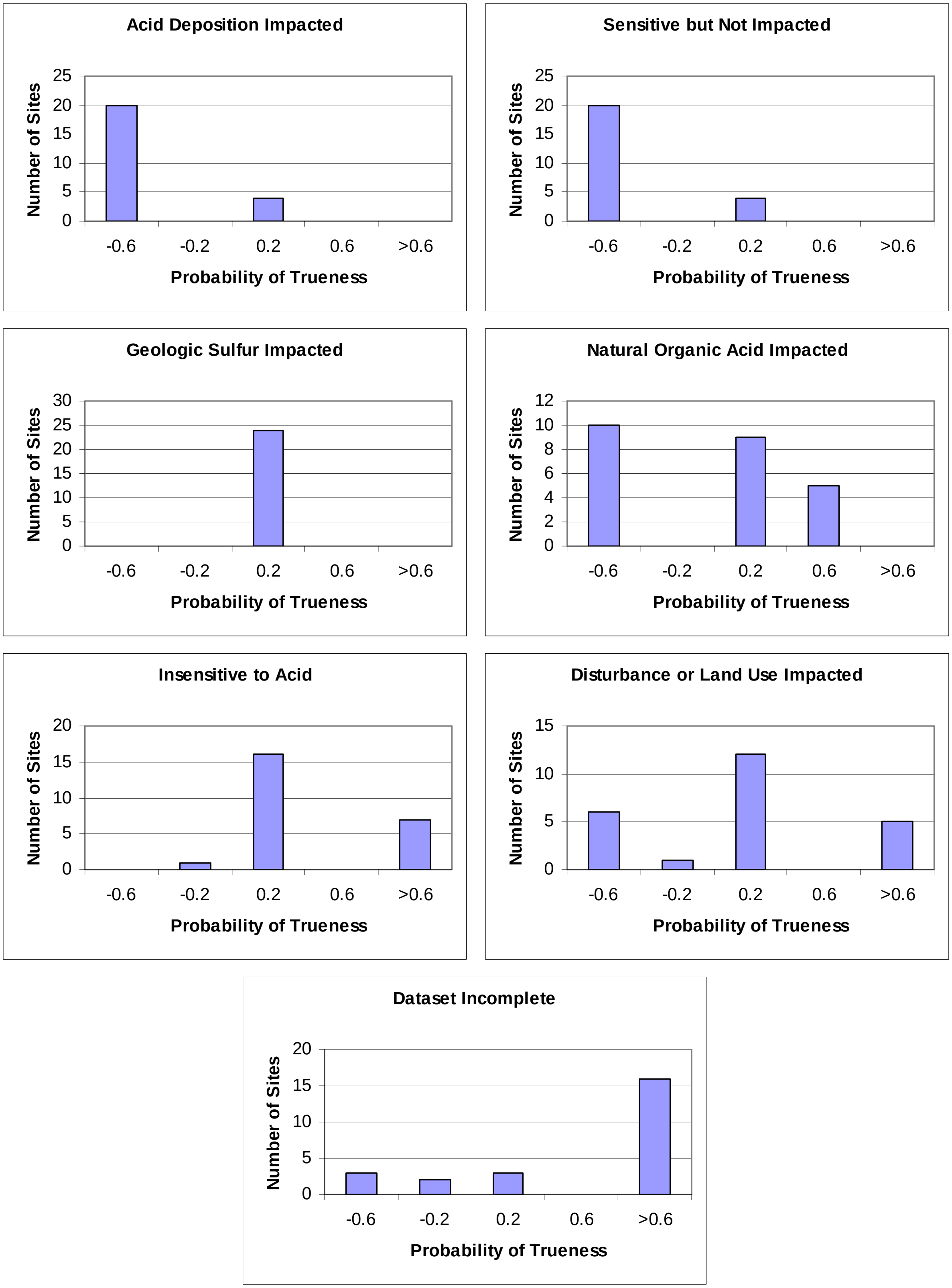
**Table 8-4: DSS Results for Extreme Lake Values - OLYM**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 20 | 20 | 0 | 10 | 0 | 6 | 3 |
| -0.59 to -0.20 | 0 | 0 | 0 | 0 | 1 | 1 | 2 |
| -0.19 to 0.20 | 4 | 4 | 24 | 9 | 16 | 12 | 3 |
| 0.21 to 0.60 | 0 | 0 | 0 | 5 | 0 | 0 | 0 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 7 | 5 | 16 |

The DSS result distribution for extreme lake values are exactly the same as that for average lake values acid deposition and unimpacted lakes sensitive to future acid deposition. Twenty lakes were found not to be impacted by acid deposition (false in the 'Acid Deposition Impacted' category). The same 20 lakes were also false in the 'Sensitive but Not Impacted' category. The results for extreme values of ANC, specific conductance, nitrate, and sulfate were similar to their average values.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

**Figure 8-6: Charts of DSS Results for Extreme Lake Values - OLYM**



Ten lakes were found to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted' category). This is due to high buffer capacity as represented by high ANC values, high specific conductance values, and high concentrations of base cations. Five lake locations were found to be impacted by natural organic acids (true in the 'Natural Organic Acid Impacted' Category), including two sites in Lake Crescent and three sites in Lake Ozette: Lake Crescent – Barnes Point (OLYM0187), Lake Crescent – Devils Point Bridge (OLYM0190), Lake Ozette – North Central (OLYM0355), Lake Ozette – South End (OLYM0366), and Lake Ozette – North End (OLYM0394). These locations are slightly acidic (pH ≈ 6) and are not impacted by nitrogen or sulfur.

Seven lakes are insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (>100 μeq/L) and high specific conductance values (≥ 30 μmhos/cm). The DSS did not make an assessment for 16 lakes. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. One lake location, Lake Ozette at Ozette (OLYM0400), was found to be sensitive to potential changes (false in the 'Insensitive to Acid' category). This location had an ANC of 60 μeq/L.

Seven lakes were found not to be impacted by disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). These lakes are well buffered with high ANC values (>100 μeq/L) and high specific conductance values (≥ 25 μmhos/cm). Five lake locations were found to be impacted by disturbance or land use (true in the 'Disturbance or Land Use Impacted' category), all in Lake Ozette: South End (OLYM0371), North Central (OLYM0376), South Central (OLYM0377), North End (OLYM0391), and at Ozette (OLYM0400). Each location had a nitrate concentration of approximately 14 μeq/L. The DSS deemed this concentration high enough than to be from nitrogen deposition alone.

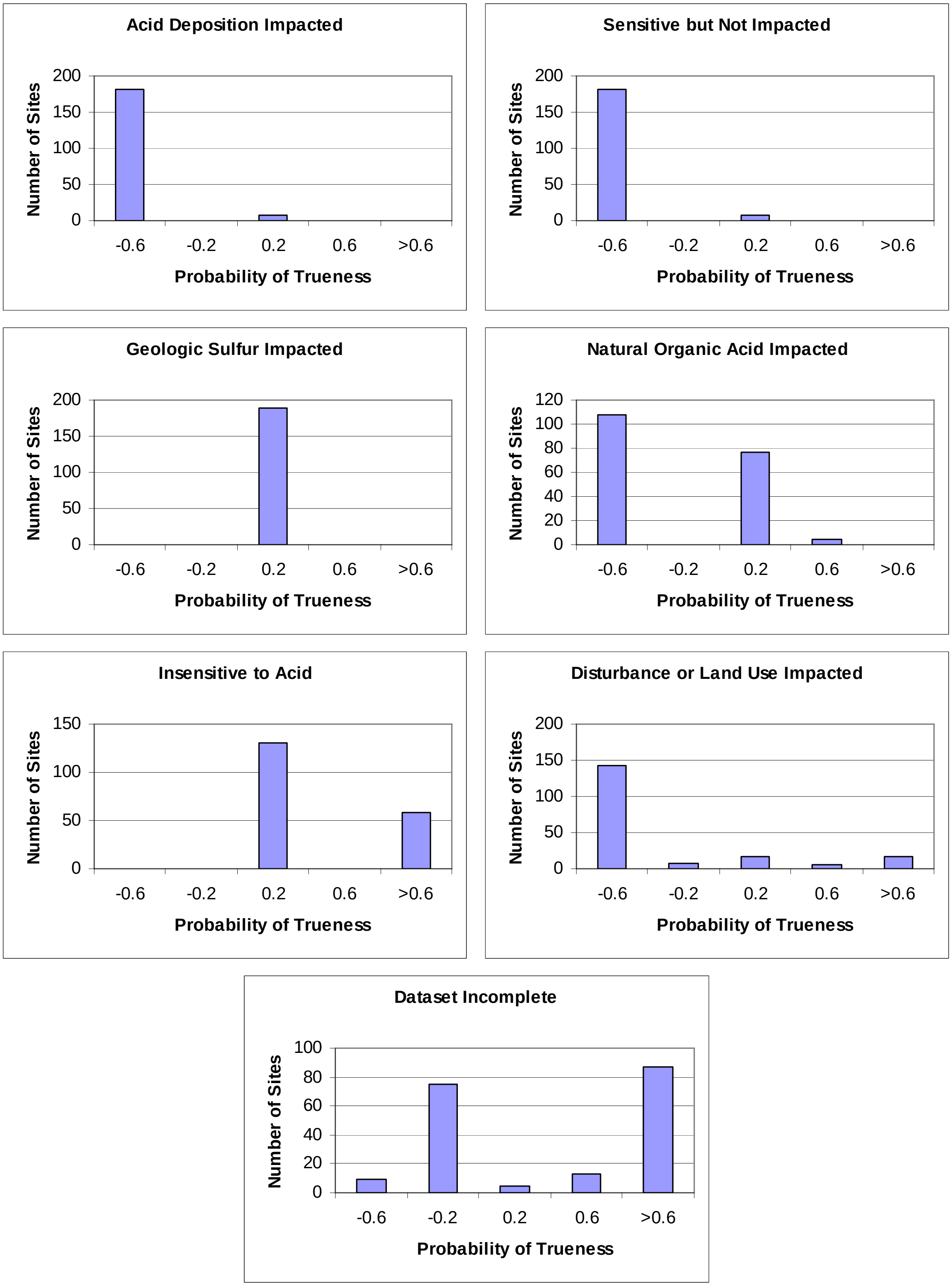
### *Streams - Average Water Chemistry Values*

Table 8-5 lists the results of the Synthesis DSS for average water chemistry values at streams in North Cascades National Park and Figure 8-7 represents this data graphically.

**Table 8-5: DSS Results for Average Stream Values - OLYM**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 181 | 181 | 0 | 108 | 0 | 143 | 9 |
| -0.59 to -0.20 | 0 | 0 | 0 | 0 | 0 | 7 | 75 |
| -0.19 to 0.20 | 8 | 8 | 189 | 77 | 131 | 16 | 5 |
| 0.21 to 0.60 | 0 | 0 | 0 | 4 | 0 | 6 | 13 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 58 | 17 | 87 |

**Figure 8-7: Charts of DSS Results for Average Stream Values - OLYM**



Nine of the stream sites had only one data parameter for the DSS. Eight of these had only a nitrate concentration. The DSS makes no recommendations for any of the categories for these streams except for 'Disturbance or Land Use Impacted'. The other site had only specific conductance. The DSS makes no recommendations for any of the categories for this stream except for 'Acid Deposition Impacted' and 'Sensitive but Unimpacted'.

Of the 181 streams for which the DSS made an assessment, all were found to not be impacted by acid deposition (false in the 'Acid Deposition Impacted' category). Most of the streams have high ANC values (> 200 μeq/L), high specific conductance (> 30 μS/cm), and high base cation concentrations (>200 μeq/L).

The same 181 streams are also not rated sensitive but unimpaired (false in the 'Sensitive but Unimpaired' category). These streams have high ANC, high specific conductance values, and high base cation concentrations, indicating a large buffering capability. The streams rate as false for this category because they are insensitive to acid deposition due to their high buffering capacity. Eight streams were deemed not to have enough information for the DSS to make a decision with any level of certainty.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

One hundred eight streams do not have evidence that high dissolved organic carbon appreciably contributed to low ANC or pH (false in the 'Natural Organic Acid Impacted' category). At those sites that have DOC data, the DOC concentration is low (< 2.25 μeq/L). As mentioned above, most of the streams have high buffering capacity, offsetting all acids, including organic acids. Four streams were considered impacted by organic acidic sources: Bob Creek (OLYM0197), Elk Creek (OLYM0239), Braden Creek (OLYM0267), and Coal Creek (OLYM0396). These locations were slightly acidic (pH ≤ 6.4) with low nitrate and sulfate concentrations, with one exception. At Elk Creek, the nitrate level was too high to feasibly be from atmospheric deposition.

The DSS did not make an assessment on the majority (131) of sites in the 'Insensitive to Acid' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. The remaining 58 streams are insensitive to acid deposition (true in the 'Insensitive to Acid' category). Indicative of these results are high ANC values (>200 μeq/L), high specific conductance values (≥ 30 μS/cm), and high base cation concentrations (>200 μeq/L).

The DSS reports 150 streams as not impacted due to disturbance or land use purposes (false in the 'Disturbance or Land Use Impacted' category. In all of these cases, the nitrate concentration was not high enough (≤ 9 μeq/L) to indicate a disturbance or land use effect. Twenty-three sites with nitrate concentrations above

12 $\mu$eq/L were considered to be impacted by a disturbance or from land use (true in the 'Disturbance or Land Use Impacted' category). These locations are listed in Table 8-6.

**Table 8-6: OLYM stream locations that are true in the 'Disturbance or Land Use Impacted' category.**

| Location ID | Location Name |
|---|---|
| OLYM0008 | Skokomish River - North Fork |
| OLYM0151 | 31N/07W-35E01 |
| OLYM0161 | Elwha River |
| OLYM0213 | Quinault River |
| OLYM0223 | Canyon Creek |
| OLYM0226 | Maple Creek |
| OLYM0227 | Dismal Creek |
| OLYM0234 | Pysht River |
| OLYM0239 | Elk Creek |
| OLYM0245 | Hoh River |
| OLYM0262 | Calawah River – North Fork |
| OLYM0265 | Queets River |

| Location ID | Location Name |
|---|---|
| OLYM0269 | Hoko River |
| OLYM0272 | Hoko River |
| OLYM0276 | Kalaloch Creek |
| OLYM0279 | Soleduck River |
| OLYM0288 | 26N/13W-20M01 |
| OLYM0292 | Gunderson Creek |
| OLYM0327 | Sail River |
| OLYM0341 | 28N/15W-23N02 |
| OLYM0353 | Umbrella Creek |
| OLYM0398 | Coal Creek |
| OLYM0399 | Ozette River |

The DSS evaluates all of the locations in terms of the completeness of the input data. Eighty-four of the sites are reasonably certain to have complete datasets. At the other 105 locations the datasets were less than complete; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Streams - Extreme Water Chemistry Values*

Table 8-7 contains the results of the Synthesis DSS of extreme water chemistry value for streams in North Cascades National Park. Figure 8-8 includes graphs of the data in this table.

**Table 8-7: DSS Results for Extreme Stream Values - OLYM**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 179 | 177 | 0 | 96 | 2 | 123 | 9 |
| -0.59 to -0.20 | 1 | 1 | 0 | 1 | 0 | 11 | 75 |
| -0.19 to 0.20 | 8 | 11 | 189 | 84 | 131 | 23 | 5 |
| 0.21 to 0.60 | 1 | 0 | 0 | 7 | 0 | 2 | 13 |
| 0.61 to 1.00 | 0 | 0 | 0 | 1 | 56 | 30 | 87 |

Of the 181 streams for which the DSS made an assessment, 180 were found to not be impacted by acid deposition (false in the 'Acid Deposition Impacted' category). Most of the streams have high ANC values (> 200 $\mu$eq/L), high specific conductance (> 30 $\mu$S/cm), and high base cation concentrations (>200 $\mu$eq/L). One stream, Mud

Creek (OLYM0232), was found to be impacted by nitrogen and sulfur deposition (true in the ‘Acid Deposition Impacted’ category). The pH at this location was 4.9.

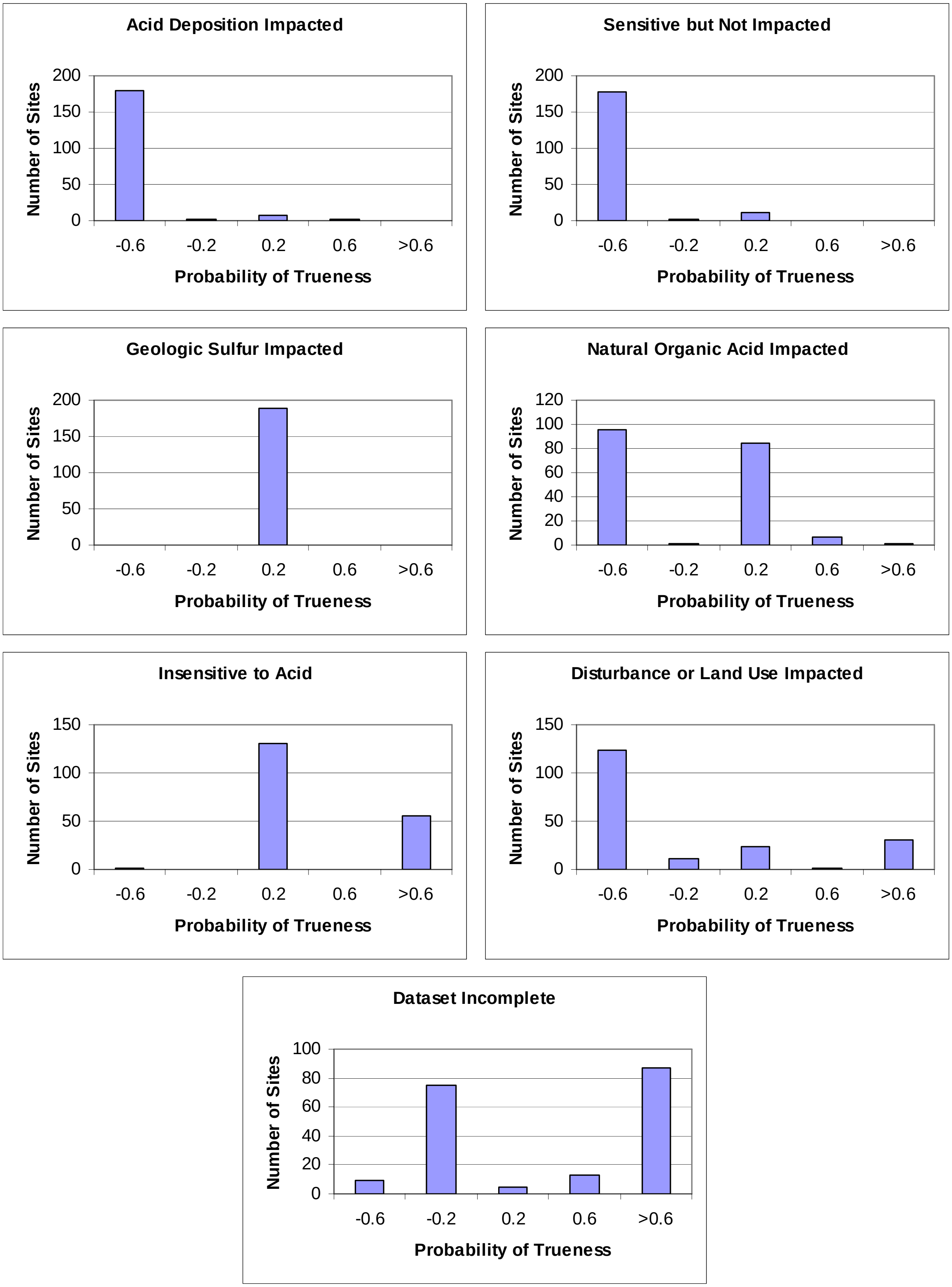
One hundred seventy-eight streams are not rated sensitive but unimpaired (false in the ‘Sensitive but Unimpaired’ category). These streams have high ANC, high specific conductance values, and high base cation concentrations, indicating a large buffering capability. The streams rate as false for this category because they are insensitive to acid deposition due to their high buffering capacity. Eleven streams were deemed not to have enough information for the DSS to make a decision with any level of certainty.

The DSS did not make an assessment about any of the locations in the ‘Geologically Sulfur Impacted’ category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

Ninety-seven streams do not have evidence that high dissolved organic carbon appreciably contributed to low ANC or pH (false in the ‘Natural Organic Acid Impacted’ category). At those sites that have DOC data, the DOC concentration is low (≤ 5 μeq/L). As mentioned above, most of the streams have high buffering capacity, offsetting all acids, including organic acids. Eight streams were considered impacted by organic acidic sources (true in the ‘Natural Organic Acid Impacted’ category). At the Queets River (OLYM0258), ANC (0 μeq/L) and specific conductance (7 μS/cm) were low, pH was slightly acidic (6.3) and the DOC concentration was relatively high (6 mg/L). At the Quinault River (OLYM214), ANC was low (20 μeq/L). The six other impacted locations were: Elwha River (OLYM0162), Bob Creek (OLYM0197), Elk Creek (OLYM0239), Braden Creek (OLYM0267), South Creek (OLYM0345), and Ellen Creek (OLYM0387). These locations were slightly acidic (pH ≤ 6.4).

The DSS did not make an assessment on the majority (131) of sites in the ‘Insensitive to Acid’ category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. Of the remaining 58 streams, 56 are insensitive to acid deposition (true in the ‘Insensitive to Acid’ category). Indicative of these results are high ANC values (>200 μeq/L), high specific conductance values (≥ 30 μS/cm), and high base cation concentrations (>200 μeq/L). Two streams were found to be sensitive to future acidity, Quinault River (OLYM214) and Queets River (OLYM0258). The ANC value at the Quinault River was 20 μeq/L and was 0 μeq/L at the Queets River. Also, specific conductance was low at the Queets River (7 μS/cm).

**Figure 8-8: Charts of DSS Results for Extreme Stream Values - OLYM**



The DSS reports 134 streams as not impacted due to disturbance or land use purposes (false in the 'Disturbance or Land Use Impacted' category. In all of these cases, the nitrate concentration was not high enough (≤ 9 μeq/L) to indicate a disturbance or land use effect. Thirty-two sites with nitrate concentrations above 12 μeq/L were considered to be impacted by a disturbance or from land use (true in the 'Disturbance or Land Use Impacted' category). These locations include the 23 listed in Table 8-6 plus 9 additional sites listed below in Table 8-8.

**Table 8-8: OLYM stream locations that are true in the 'Disturbance or Land Use Impacted' category using extreme water chemistry values only.**

| Location ID | Location Name |
|---|---|
| OLYM0162 | Elwha River |
| OLYM0218 | West Twin Creek |
| OLYM0219 | West Twin Creek |
| OLYM0237 | Hibbard Creek |
| OLYM0247 | Clallam River |

| Location ID | Location Name |
|---|---|
| OLYM0258 | Queets River near Clearwater |
| OLYM0263 | Queets River |
| OLYM0280 | Soleduck River |
| OLYM0404 | Petroleum Creek |

### Analysis

## Conclusion

The Horizon database for Olympic NP is skewed by a large number of lake samples (8 of 24) being collected from Lake Crescent, the largest lake in the park. The samples are from several locations about the lake. The only data for this lake that are used in the DSS are specific conductance and pH. Because the specific conductance is high (about 125 uS/cm) and the pH is about 7 the DSS is limited to concluding that there is little impact or potential impact from acid rain, natural organic acid. Impacts from land use disturbance and geologic sulfur are uncertain because of lack of data on nitrate and sulfate.

Similarly 12 of 24 samples were collected from multiple sites about Lake Ozette. This lake has elevated nitrate concentrations (5-12 ueq/L) but pH of about 7, ANC of 100 ueq/L or more, specific conductance of 30 uS/cm or more, and a SBC of 390 ueq/L (single sample only). Sulfate concentration in a single sample is 78 ueq/L. Because the various samples have different numbers of constituents used by the DSS the results can vary. For example, samples having data for ANC or specific conductance are judged definitely to not be acid deposition impacted or sensitive to acid deposition impact (probability of trueness of –1), whereas samples lacking these two constituents are given a probability of 0 for those categories. It is likely that all samples would have had similar values for ANC or specific conductance; thus, all samples probably would have been judged unimpacted by and insensitive to acid deposition.

Interestingly, for samples from Lake Ozette the DSS judged impact from natural organic acids with probability of trueness from –1 to 0 for all but one sample in spite of the complete absence of data for DOC. A probability of trueness of 0 was assigned to samples having data only for nitrate, whereas a probability of trueness of –1 was assigned to most samples having data for at least ANC or specific conductance. Probably, ANC and specific conductance are in a range where the DSS assigns rapidly changing probability of trueness for impacts from natural organic acids in response to small changes in these variables and absence of data for DOC. Thus, the DSS seems to decide with certainty that there is no impact for samples with ANC above about 100 ueq/L or specific conductance above about 35 uS/cm but judges some impact possible at lower ranges for these parameters. Stream samples tend to have more parameters used by the DSS so the possible causes for variation in classification for this category are slightly more complex; however, all but one sample are classified as either –1 or 0 probability of trueness, with 0 being assigned to those samples having the fewest parameters used by the DSS.

Samples from Lake Ozette also seem to be in a critical range for possible impact from disturbance. The DSS assigns probability of trueness for the category ranging from –1 to +0.4 over a range of nitrate concentration from 5-12 ueq/L. This holds true for stream samples, which are assigned a probability of trueness for this category of +0.4 to 1 for samples having nitrate concentrations of 12-34 ueq/L.

DSS results for streams indicates little sensitivity to acidic deposition or to geologic sulfur but only about 28% of stream samples have data for ANC and only 46% have data for sulfate. Some possible effect of natural organic acids is judged to occur but only 4% of stream samples have data for DOC; thus, results for this category should be considered preliminary. The DSS judged impact from disturbance or land use to be more likely than impacts from other categories and almost all samples (86%) have data for nitrate.

# Chapter 9 – - Air and Water Quality in the Rocky Mountain Region

The information in this section was taken from the Assessment of Air Quality and Air Pollutant Impacts in National Parks of the Rocky Mountains and Northern Great Plains (Peterson et al. 1998). The complete report is available on the web at the following site:

http://www2.nature.nps.gov/air/pubs/

## Environmental Setting

The Rocky Mountain region from northern Colorado to northern Montana encompasses a wide variety of landscapes and ecosystems. Geology, soils, aquatic systems, vegetation, and fauna are highly variable at both large and small spatial scales due to the complex mountainous topography of this region. The Rocky Mountains are rugged glaciated mountains with many peaks up to 4,500 m in elevation. Mountainous topography is generally highly dissected with intervening valleys and plateaus. Geology is spectacularly varied with a great diversity of igneous, metamorphic, and sedimentary bedrock of various ages. Glacial till is found in many locations as a result of various glacial advances during the Pleistocene. The presence of glaciers in many high mountain valleys and cirques attests to the geomorphically dynamic landscapes of the Rockies.

The climate of the southern and central Rockies is considered to be a semiarid steppe regime in which there is considerable variation in precipitation with altitude. Total precipitation is moderate but greater than in the plains regions to the west and east. Foothill regions annually receive only 25 to 50 cm of rainfall, while higher elevations may receive as much as 100 cm. In the higher mountains, a major portion of annual precipitation is snow. Climate is strongly affected by prevailing winds, resulting in generally wetter western slopes and drier eastern slopes.

In the northern Rockies, annual precipitation ranges from 50 to 100 cm, with much of it falling as snow. Summers generally are dry because prevailing westerly winds during this season transport relatively dry air masses from the Pacific Northwest (Bailey 1980).

## Air Quality

Air pollution in urban areas adjacent to the Rockies, especially at locations east of the Front Range in Colorado, has increased considerably during the last 30 to 40 years. Dispersion and transport of pollutants vary locally.

Air quality in western portions of Wyoming is influenced by emissions from these states. Colorado and Utah have the highest total $NO_X$ emission levels, mainly from fossil fuel combustion by electric power utilities and on-road vehicles. Colorado and Wyoming both have annual $SO_2$ emissions exceeding 100,000 tons/year. In these states, electric utilities are the major sources of $SO_2$, followed by industrial fuel combustion (including oil and gas refining) and mining operations.

Colorado has numerous $SO_2$ point sources (although many are too small to be regulated) near park boundaries, posing a potential threat to park resources. $SO_2$ emissions may affect resources in ROMO due to the proximity of numerous sources in the Denver area and Yampa Valley west of the park. Despite its low population, Wyoming has a large number of $SO_2$ point sources scattered throughout the state, with several located 100 km east of YELL. Prevailing winds from the southwest may protect the park from the impact of these neighboring emissions sources. In general, YELL and GRTE are remote from upwind urban and industrial development and therefore experience excellent air quality.

There is no single regional emission problem that strongly affects all national parks in the Rocky Mountains. Some parks are subject to deposition of pollutants from urban areas, some are affected by long-distance transport of pollutants from industrial facilities and electric utilities, and some are affected by local sources. Therefore, the quantity of emissions received and the potential threat to natural resources must be analyzed individually for each park.

There are serious concerns about air quality at ROMO because of increased levels of N deposition, a potential threat to terrestrial and aquatic systems. Most of the emissions are from urban areas in the Front Range of the Rocky Mountains between Colorado Springs and Fort Collins and especially the Denver metropolitan area.

Emission threats to YELL and GRTE are relatively minor. Most deposition in this area is due to long-distance transport from sources to the west. Emissions data for Wyoming indicate that the state produces large quantities of $NO_x$ and $SO_2$. Most of these emissions are from industrial and power-generation facilities to the east of YELL and GRTE; only relatively uncommon easterly winds would transport these pollutants into the parks.

## Lake and Stream Chemistry

Although aquatic effects from N deposition have not been studied as thoroughly as those from S deposition, concern has been expressed regarding the role of nitrate ($NO_3^-$) in acidification of surface waters (particularly during hydrologic episodes), the role of $NO_3^-$ in the long-term acidification process, the contribution of ammonium ($NH_4^+$) from agricultural sources to surface water acidification, and the potential for anthropogenic N deposition to stimulate eutrophication of freshwaters and estuaries (e.g., Sullivan 1993, Wigington et al. 1993, Sullivan et al. 1997).

Atmospheric deposition of S and N (as $NO_3^-$ and as $NH_4^+$, which can be quickly nitrified to $NO_3^-$) often cause increased concentrations of $SO_4^{2-}$ in drainage waters and can, in some cases, cause increased concentrations of $NO_3^-$. An increase in the concentration of either of these mineral acid anions will generally result in a number of additional changes in water chemistry. These can include:

- Increased concentration of base cations ($Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$)
- Decreased concentration of acid neutralizing capacity (ANC)
- Increased concentration of hydrogen ion ($H^+$) (decreased pH)
- Increased concentration of dissolved Al

Greatly increased concentrations of $H^+$ and/or Al occur only in response to higher concentrations of $SO_4^{2-}$ or $NO_3^-$ when ANC has decreased to near or below zero. At higher ANC values, $SO_4^{2-}$ or $NO_3^-$ concentrations are mainly balanced by increasing base cation concentrations and some decrease in alkalinity. High concentrations of $H^+$ or Al can be toxic to fish and other aquatic biota.

If $NO_3^-$ leaches into stream or lakewater as a result of increased N deposition, the result can be eutrophication or acidification. If N is limiting for aquatic primary production, the added $NO_3^-$ will generally result in increased algal productivity, which can cause disruption of aquatic community dynamics. If N is not limiting (P or some other nutrient can be limiting, for example), then the added $NO_3^-$ will remain in solution, possibly leading to acidification.

Most lakes receive the majority of their hydrologic input from water that has previously passed through the terrestrial catchment. As long as N retention in the terrestrial system remains high, as is generally the case for forested ecosystems, N concentrations in lakes will remain low in the absence of contributions from land use (e.g., agriculture) or other pollution sources. However, if N retention in the catchment is low and the lake has not yet acidified, N deposition can in some cases increase primary production. This is most likely to happen in groundwater recharge lakes where nutrient inputs are derived largely from deposition to the lake surface. Lakes that are most likely to be low in base cations (therefore potentially sensitive to acid deposition) and also N-limited are often systems overlaying volcanic bedrock (these rocks may be high in P).

# Chapter 10 - Grand Teton National Park

## Background

### Description

Grand Teton National Park (GRTE) consists of 126,530 ha located in northwestern Wyoming. GRTE is surrounded by Bridger-Teton and Targhee National Forests, and lies 10 km south of Yellowstone National Park (YELL). The Teton Mountains, a 67-km long range, stretch along a north-south line and reach a height of 4,230 m. The Teton Mountain Range slopes steeply down to Jackson Hole, an intermountain valley about 75 km long and 10 to 20 km wide. The Snake River flows south through the valley, which varies from about 1,800 to 2,100 m elevation. To the east of Jackson Hole are the Absaroka Mountains and to the southeast the Gros Ventre Mountain Range. The lower elevation relief is characterized by several terrace levels and glacial moraines, especially on the west side of the valley. Glacial ice has carved numerous U-shaped valleys and cirques. Erosion has formed deep V-shaped valleys within the mountain range. The park drains into the Snake River, a tributary of the Columbia River.

There is a significant north-south gradient in annual precipitation values in the park region, with highest amounts to the north and lowest amounts to the south in the rain shadow of the high peaks of the Teton Mountains. Winter and spring precipitation tends to be highest (Dirks 1975). Average annual precipitation varies from about 41 cm at Jackson to about 154 cm near the summit of the Teton Mountains. Average annual snowfall varies from about 2 m at Jackson to over 7.7 m at high elevation. Snowmelt generally peaks in May and June. Thunderstorms are frequent during summer.

### Deposition

There is little industrial activity and low population in northwestern Wyoming, resulting in good air quality. Most of the industrial activity in Wyoming occurs in the eastern counties near the cities of Gillette and Casper, and in the southwestern counties around Rock Springs. Oil and gas processing, electric utility power plants and industrial fossil-fuel combustion in southwestern Wyoming and southeastern Idaho are the major sources of gaseous pollutants and deposition to the GRTE area. There may also be some long-range transport of pollutants from the Salt Lake City area. Annual emissions of gaseous $SO_2$, $NO_x$ and VOC in Wyoming are mainly from fossil fuel burning by industrial sources and levels are moderate relative to other Western states.

Potential future impacts on GRTE's natural resources could be caused by the following sources of pollution: (1) increasing residential and business development in Jackson Hole south of the park, including woodburning stoves and fireplaces, automobiles, and air traffic; (2) increasing use of prescribed burning in and around Jackson Hole; (3) proposed oil and gas development and associated activities south, east, and west of the park (including on BLM land); (4) agricultural practices in Idaho west of the park; and (5) metropolitan and industrial development along the western slope of the Wasatch Mountains in the Salt Lake City, Utah area.

There is no deposition monitoring station in GRTE for S and N. However, there is a NADP monitoring station in YELL to the north. Both parks are exposed to the same general air masses, and both experience prevailing winds mostly from the southwest. There are no large point sources of N or S adjacent to either park that might cause major differences in local deposition. Therefore deposition data from YELL is relied upon to evaluate deposition issues for GRTE.

Precipitation volume and chemistry have been monitored at the NADP site at Tower Junction in YELL since 1980. Annual precipitation amounts are generally in the range of 30 to 45 cm per year at this site. The concentrations of $SO_4^{2-}$, $NO_3^-$, and $NH_4^+$ in precipitation are low, with each generally below 10 µeq/L. The combined low amount of precipitation and low concentrations of acid-forming precursors in wetfall results in very low levels of S and N deposition. Sulfur deposition is generally well below 1 kg/ha/yr, and N deposition is seldom above this amount.

## Water Quality

There are about 90 alpine and subalpine lakes and ponds in the park located above about 2700 m elevation. The majority are in remote areas that are difficult to access (Gulley and Parker 1985). Most are less than 10 ha in area. Larger lakes are found at lower elevation. Many lakes in the park were formed behind the terminal moraines of glaciers. The multitude of small lakes and streams are distributed throughout the mountainous areas of the park, especially in the central and southern portions of the range.

Alpine lakes in GRTE exhibit a range of characteristics that contribute to their sensitivity to potential acidic deposition impacts (e.g., Marcus et al. 1983): bedrock resistant to weathering, shallow soil, steep slope, low watershed to lake surface area ratio, high lake flushing rate, high precipitation, high snow accumulation, and short growing season. Sensitive lakes are located throughout most high elevation portions of the park, but especially in the north-central portion of the Grand Teton Mountain Range.

Surface water alkalinity values tend to be high throughout most of the low elevation areas of the park. Lakes and streams with alkalinity less than 400 µeq/L are generally restricted to the high mountain areas near the western border of the park.

Moraine lakes tend to be larger than the mountain lakes and are likely insensitive to acidification from acidic deposition. Similarly, all of the four valley lakes sampled had high specific conductance (greater than 100 µS/cm) and pH greater than 8.5 and would not be sensitive to acidic deposition.

Gulley and Parker (1985) concluded that the alpine basins of the park exhibited remarkably homogeneous water chemistry. This occurred because of the similar physical, geochemical, and vegetative characteristics of the alpine basins. All basins where lakes were sampled, except Schoolroom Lake and Avalanche Canyon, had bedrock geology of Precambrian gneiss, schist, and granite.

Only a few alpine lakes sampled by Gulley and Parker (1985) had specific conductance greater than 30 µS/cm. For example, Schoolroom Lake, located at the base of Schoolroom Glacier, had a conductivity of 57 µS/cm, three times higher than other alpine lakes in the park, and total hardness equal to 31 mg/L as $CaCO_3$. Glacial silt from sedimentary rocks in the catchment at Schoolroom Lake affects the water chemistry of the lake by making its concentration of base cations higher than other alpine lakes in the region. In contrast, Delta Lake is situated directly below Teton Glacier, but is much more dilute (total hardness equal to 4.0 mg/L as $CaCO_3$). Like Schoolroom Lake, Delta Lake receives large contributions of glacial silt. Teton Glacier resides on granite, gneiss, and schist, whereas Schoolroom Glacier is on limestone and dolomite (Gulley and Parker 1985).

## Aquatic Chemistry Data and DSS Results

### Horizon Report

The Horizon report was released for Grand Teton NP in October 2001. The report contains information on 679 water bodies in the park. More water bodies exist, but were not sampled. 85% of water bodies in the report contained data relevant to the DSS. The report details 159 lakes, 475 streams, and 45 other water bodies in Grand Teton NP. Table 10-1 lists the number of sites that have data for each DSS component. The numbers indicate that data for all waters, with the exception of specific conductance and pH data, is relatively incomplete.

**Table 10-1: Chemistry Component Summary - GRTE**

| | Total | Lakes | Streams | Other |
|---|---|---|---|---|
| Number | 679 | 159 | 475 | 45 |
| Conductance | 489 | 112 | 338 | 39 |
| pH | 494 | 133 | 322 | 39 |
| ANC | 204 | 93 | 96 | 15 |
| DOC | 14 | 2 | 11 | 1 |
| Nitrate | 166 | 33 | 106 | 27 |
| Base Cations | 255 | 85 | 137 | 33 |
| Sulfate | 118 | 13 | 81 | 24 |

Both lakes and streams generally lack complete sets of data (Table 10-2). Thirty-seven percent of lake sites and 68% of stream sites had two or fewer data elements used by the DSS. Eight percent of lake sites and 14% of stream sites and had four or more of these data elements. This highlights the need for a standard set of chemical analyses to be performed on any water samples taken in the park.

**Table 10-2: Number of Elements Summary - GRTE**

| # of Elements | Total | Lakes | Streams | Springs |
|---|---|---|---|---|
| 0 | 100 | 15 | 83 | 2 |
| 1 | 81 | 16 | 63 | 2 |
| 2 | 207 | 28 | 175 | 4 |
| 3 | 101 | 19 | 74 | 8 |
| 4 | 89 | 69 | 13 | 7 |
| 5 | 33 | 8 | 9 | 16 |
| 6 | 55 | 2 | 47 | 6 |
| 7 | 13 | 2 | 11 | 0 |

Of the 629 sites that had any data collection, including parameters not used by the DSS, 15 sites were last sampled in the 1950s or before, 34 in the 1960s, 357 in the 1970s, 78 in the 1980s, and 145 in the 1990s. The lake data, on average, were newer than the stream data, with 45% of lakes last sampled during the 1980s and 27% in the 1990s. In contrast, 68% of streams were last sampled in the 1970s. Most of the data in this report is 15 years old or older and may not indicate current water chemistry conditions. Additional sampling should take place so that the DSS can have up to date data for making recommendations.

Of the 204 locations that had alkalinity data, sampling occurred only once at 56% of them. At these locations, the mean and extreme ANC values are the same. Alkalinity results were based on more than 10 samples at only 5% of all locations. More frequent future sampling will aide in gaining a more robust data set for entry into the DSS.

## ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

### *Mean ANC*

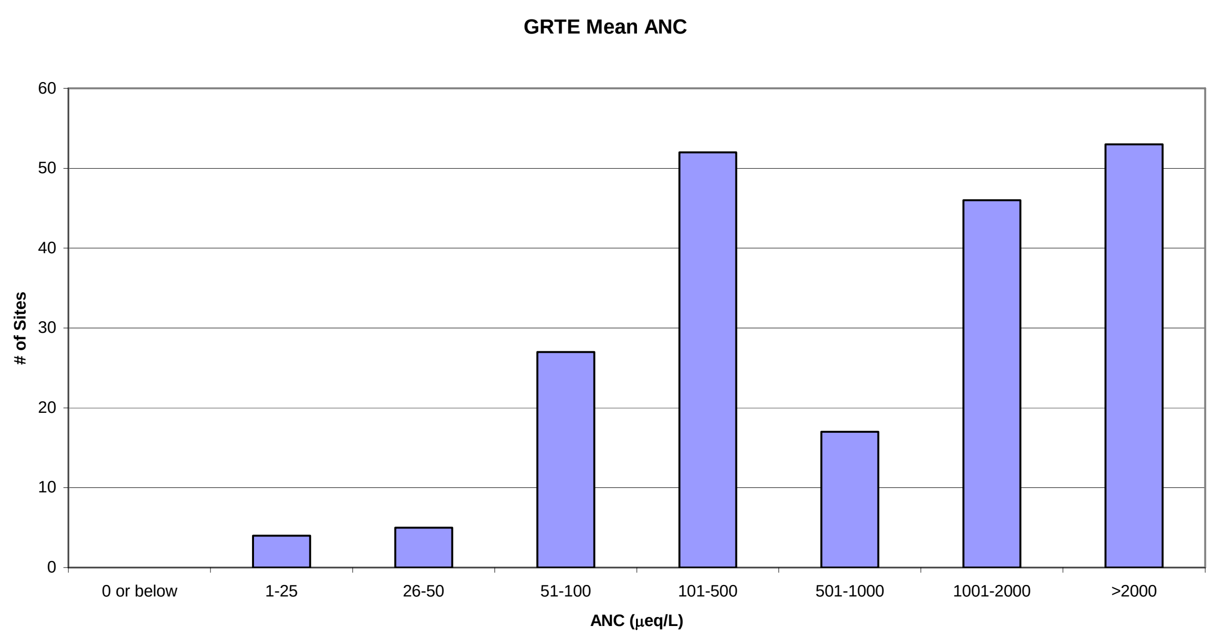
Of the 204 sampling locations which contained data for ANC calculations, 4% had a mean ANC below 50 μeq/L. These nine locations are listed in Table 10-3.

**Table 10-3: Locations with mean ANC less than 50 μeq/L- GRTE**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| GRTE0129 | Pond #ND12; ~ 1.5 km west of Static Peak | 20 |
| GRTE0137 | Lake #ND10; Timberline Lake | 20 |
| GRTE0188 | Lake #SC10; Iceflow Lake | 40 |
| GRTE0301 | Pond #PB20; ~ 0.33 mi southwest of Holly Lake | 29 |
| GRTE0353 | Pond #MO23; ~ 0.25 mi east of Cirque Lake | 8 |
| GRTE0355 | Pond #MO24; ~ 0.33 mi east of Cirque Lake | 40 |
| GRTE0361 | Pond #MO01; ~ 0.10 mi north of Cirque Lake | 16 |
| GRTE0408 | Lake #SS10; Dudley Lake | 40 |
| GRTE0454 | Pond #WB30; ~ 1.50 mi west of Talus Lake | 40 |

Figure 10-1 contains a graph of the frequency distribution of mean ANC values in Grand Teton NP.

**Figure 10-1: Frequency Distribution of Mean ANC Values - GRTE**



*Minimum ANC*

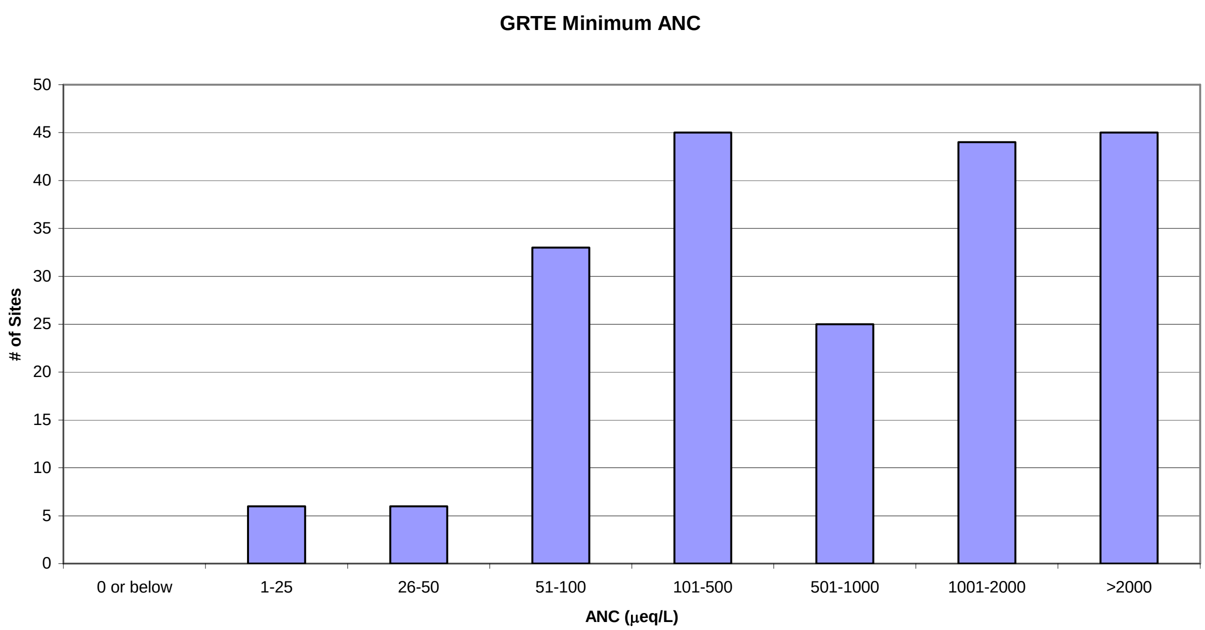
Of the 204 sampling locations which contained data for ANC calculations, 6% had minimum ANCs below 50 μeq/L, 3% below 25 μeq/L. These locations are listed in Table 10-4.

**Table 10-4: Locations with minimum ANC less than 50 μeq/L - GRTE**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| GRTE0129 | Pond #ND12; ~ 1.5 km west of Static Peak | 20 |
| GRTE0137 | Lake #ND10; Timberline Lake | 20 |
| GRTE0154 | South Fork of Avalanche Canyon | 20 |
| GRTE0168 | Lake #GR11; Bradley Lake | 40 |
| GRTE0188 | Lake #SC10; Iceflow Lake | 40 |
| GRTE0198 | Lake #GR13; Surprise Lake | 40 |
| GRTE0301 | Pond #PB20; ~ 0.33 mi southwest of Holly Lake | 18 |
| GRTE0353 | Pond #MO23; ~ 0.25 mi east of Cirque Lake | 8 |
| GRTE0355 | Pond #MO24; ~ 0.33 mi east of Cirque Lake | 40 |
| GRTE0361 | Pond #MO01; ~ 0.10 mi north of Cirque Lake | 16 |
| GRTE0408 | Lake #SS10; Dudley Lake | 40 |
| GRTE0454 | Pond #WB30; ~ 1.50 mi west of Talus Lake | 40 |

Figure 10-2 contains a graph of the frequency distribution of minimum ANC values in Grand Teton NP.

**Figure 10-2: Frequency Distribution of Minimum ANC Values - GRTE**



## Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

### *Lakes - Average Water Chemistry Values*

Table 10-5 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in Grand Teton NP and Figure 10-3 includes graphical representations of this data.

Three of the lake sites had only one data parameter for the DSS (nitrate concentration). The DSS makes recommendations with no certainty for all of the categories for these lakes except for Disturbance or Land Use Impacted.

**Table 10-5: DSS Results for Average Lake Values - GRTE**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 111 | 107 | 90 | 93 | 9 | 32 | 2 |
| -0.59 to -0.20 | 10 | 1 | 32 | 1 | 12 | 0 | 8 |
| -0.19 to 0.20 | 23 | 35 | 12 | 49 | 51 | 111 | 2 |
| 0.21 to 0.60 | 0 | 1 | 0 | 1 | 1 | 0 | 14 |
| 0.61 to 1.00 | 0 | 0 | 10 | 0 | 71 | 1 | 118 |

Of the 121 lakes for which the DSS made an assessment about acid deposition, all of them are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category). These lakes have high ANC (> 80 $\mu$eq/L), specific conductance (> 15 $\mu$S/cm), and base cation concentrations (> 150 $\mu$eq/L) values. None of the lakes were identified as being acid deposition impacted (true in the 'Acid Deposition Impacted' category).

The DSS identified 108 lake locations that are classified as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These lakes have high ANC and specific conductance values, and high base cation concentrations. Only 1 lake was found to be sensitive but not impacted (true in the 'Sensitive but Unimpacted' category): Grassy Lake Reservoir (GRTE0642). This location had moderate buffering capabilities, but low nitrate and sulfur concentrations.

The DSS considered 122 of the lakes locations to not show acid affects from geologic sulfur (false in the 'Geologic Sulfur Impacted' category). This is mainly attributable to the substantial buffer capacity of these lakes. The few sites that have sulfate values indicate concentrations commonly are very low (< 5 $\mu$eq/L). Ten locations were found to show acidic effects from geologic sulfur (true in the 'Geologic Sulfur Impacted' category) (Table 10-6). These locations have moderate to high sulfate concentrations, but have neutral or slightly basic pH (≥ 7).

**Table 10-6: GRTE locations rated true in the "Geologic Sulfur Impacted" category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| GRTE0065 | Grizzly Lake | GRTE0404 | Emma Matilda Lake |
| GRTE0074 | Lower Slide Lake | GRTE0458 | Jackson Lake |
| GRTE0262 | Jenny Lake | GRTE0467 | Two Ocean Lake |
| GRTE0352 | Trapper Lake | GRTE0553 | Hidden Lake |
| GRTE0384 | Jackson Lake | GRTE0640 | Grassy Lake Reservoir |

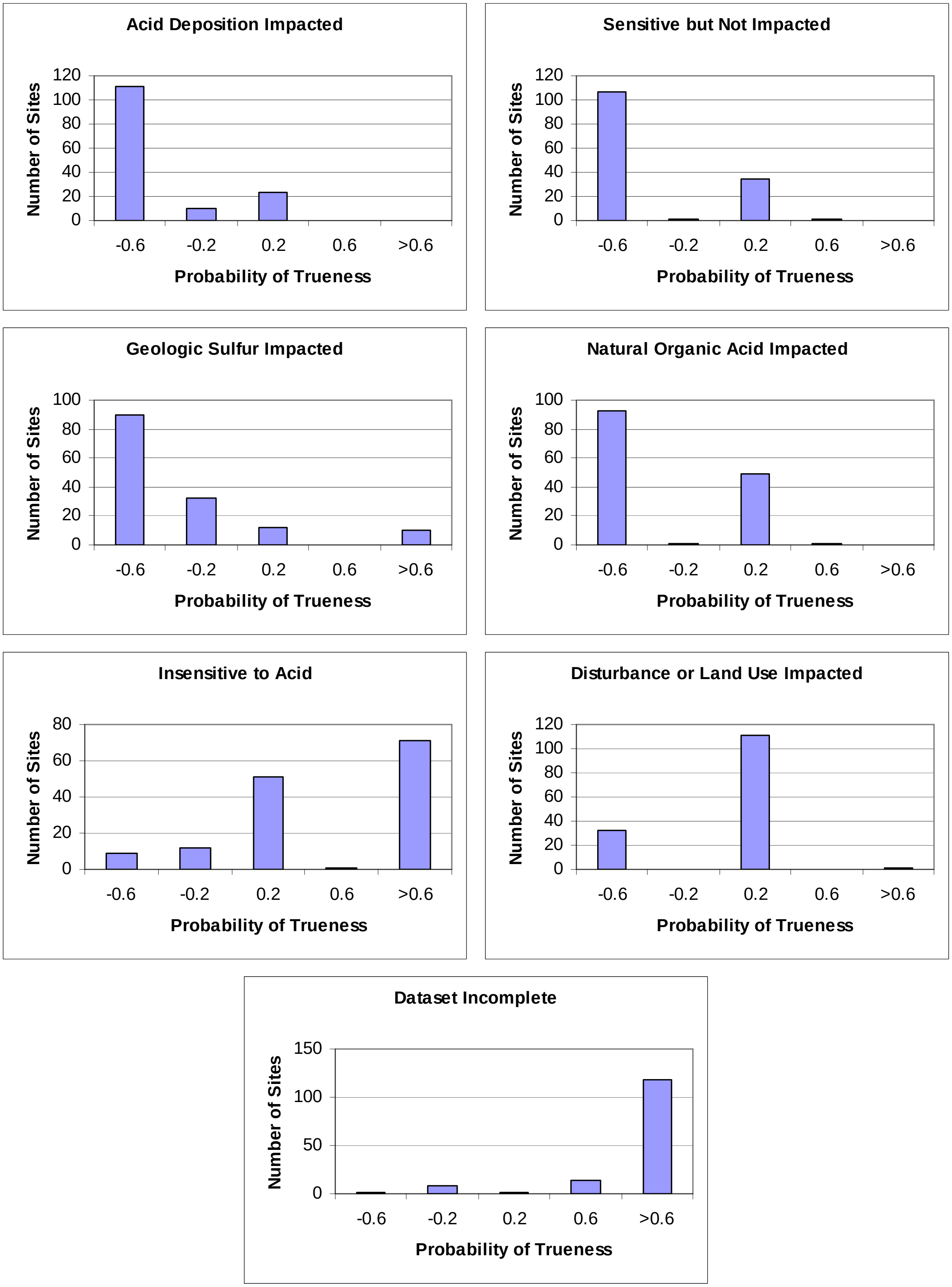
At 94 lakes, the DSS found the locations to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted' category). This is due to high buffer capacity as represented by high ANC values, high specific conductance values, and high concentrations of base cations. One lake, Pond #MO23 (GRTE0353), was found probably to be impacted by natural organic acids (true in the 'Natural Organic Acid Impacted' Category). This location has extremely poor buffering capacity, as indicated by low ANC (8 μeq/L), specific conductance (7 μS/cm), and base cation concentration (13 μeq/L).

The DSS identified 72 lakes as insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (>100 μeq/L) and high specific conductance values (≥ 20 μmhos/cm). The 21 lakes listed in Table 10-7 were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category).

**Table 10-7: GRTE lake locations rated false in the 'Insensitive to Acid' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| GRTE0093 | Forget-Me-Not Lake | GRTE0353 | Pond #MO23 |
| GRTE0106 | Pond #SD01 | GRTE0355 | Pond #MO24 |
| GRTE0129 | Pond #ND12 | GRTE0361 | Pond #MO01 |
| GRTE0131 | Pond #ND11 | GRTE0408 | Dudley Lake |
| GRTE0137 | Timberline Lake | GRTE0449 | Pond #NS14 |
| GRTE0180 | Pond# SC01 | GRTE0450 | Pond #NS13 |
| GRTE0188 | Iceflow Lake | GRTE0454 | Pond #WB30 |
| GRTE0301 | Pond #PB20 | GRTE0461 | Pond #WB02 |
| GRTE0308 | Lake Solitude | GRTE0476 | Pond #WB22 |
| GRTE0315 | Pond #LE22 | GRTE0479 | Pond #WB21 |
| GRTE0350 | Cirque Lake | | |

**Figure 10-3: Charts of DSS Results for Average Lake Values - GRTE**



Only 32 lakes were found to not suffer from the results of disturbance or land use (false in the ‘Disturbance or Land Use Impacted’ category). In all of these cases, the nitrate concentration was ≤ 6 μeq/L. A single location, Jackson Lake (GRTE0519), was found possibly to be impacted by acid due to disturbance or land use practices (true in the ‘Disturbance or Land Use Impacted’ category). The nitrate concentration at this location is 21.4 μeq/L. The DSS did not make an assessment for 111 lakes. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS evaluates all of the locations in terms of the completeness of the input data. Ten locations have complete datasets. The other 134 lake locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Lakes – Extreme Water Chemistry Values*

Table 10-8 lists the results of the DSS for extreme values of water chemistry parameters in lakes in GRTE. Figure 10-4 graphically represents these results.

**Table 10-8: DSS Results for Extreme Lake Values - GRTE**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 104 | 100 | 85 | 88 | 11 | 31 | 2 |
| -0.59 to -0.20 | 14 | 2 | 36 | 0 | 15 | 0 | 8 |
| -0.19 to 0.20 | 26 | 41 | 13 | 55 | 51 | 111 | 6 |
| 0.21 to 0.60 | 0 | 1 | 0 | 1 | 0 | 1 | 13 |
| 0.61 to 1.00 | 0 | 0 | 10 | 0 | 67 | 1 | 115 |

The DSS result distribution for extreme lake values are very similar for the ‘Acid Deposition Impacted’, ‘Sensitive but Unimpacted’, ‘Geologic Sulfur Impacted’, and ‘Natural Organic Acid Impacted’ categories as they are for average lake values. The same locations that were true in these categories for average lake conditions were true for extreme lame chemistry values. This occurred for two reasons. First, results at 56% of all locations came from a single test at that location. Therefore, the mean value for a parameter and its minimum value are the same.

The DSS found 67 lakes to be insensitive to future acid introduction (true in the ‘Insensitive to Acid’ category). These waters all have high levels of buffering capacity. Twenty-six of the locations were classified as being sensitive to future acidic episodes (false in the ‘Insensitive to Acid’ category) (Table 10-9). Most of these locations have low buffering capacity, indicated by low ANC (≤ 60 μeq/L), low specific conductance (< 15 μS/cm), and low base cation concentrations (< 100 μeq/L).

**Figure 10-4: Charts of DSS Results for Extreme Lake Values - GRTE**

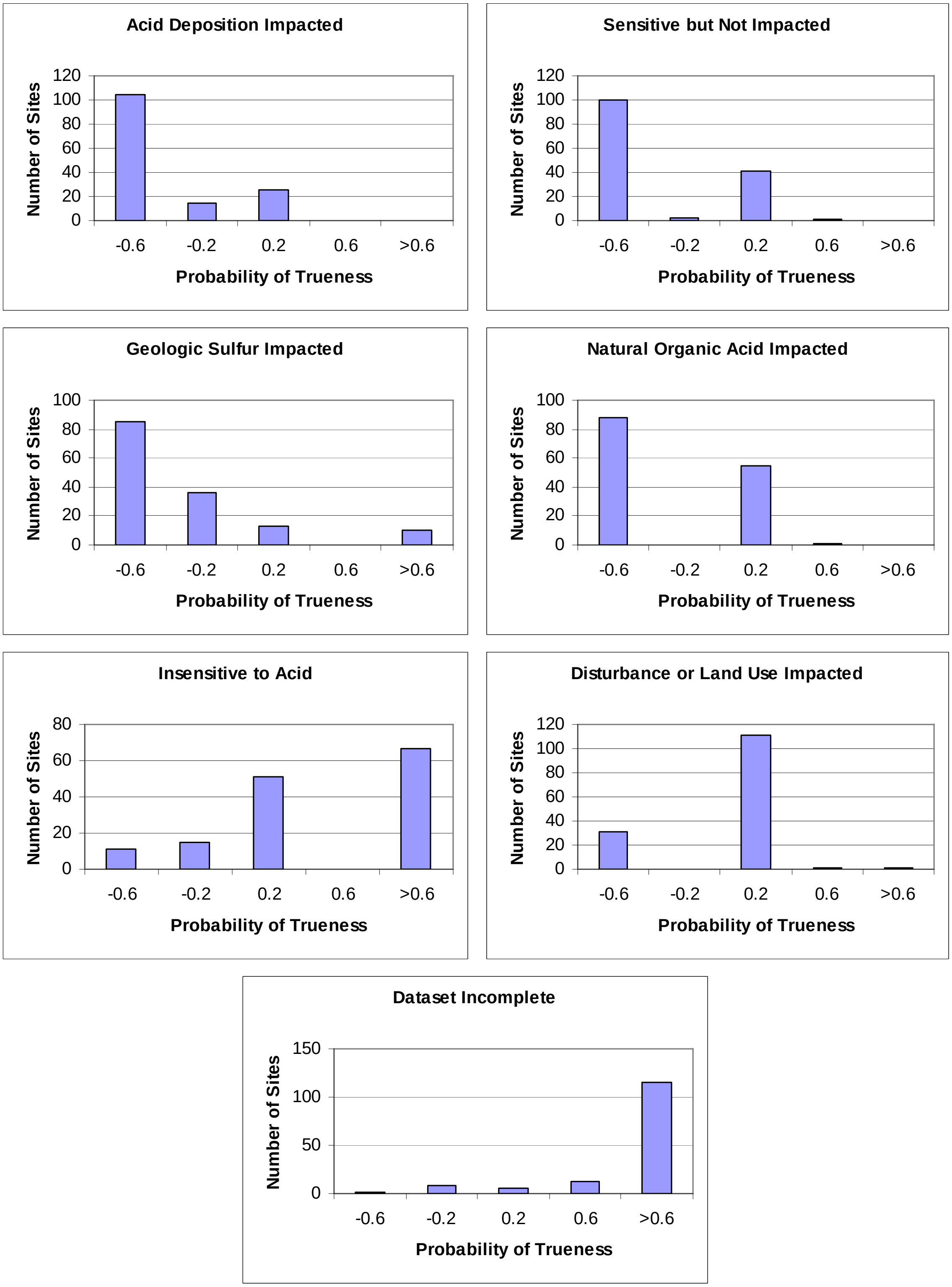


**Figure 10-5: Charts of DSS Results for Average Stream Values - GRTE**

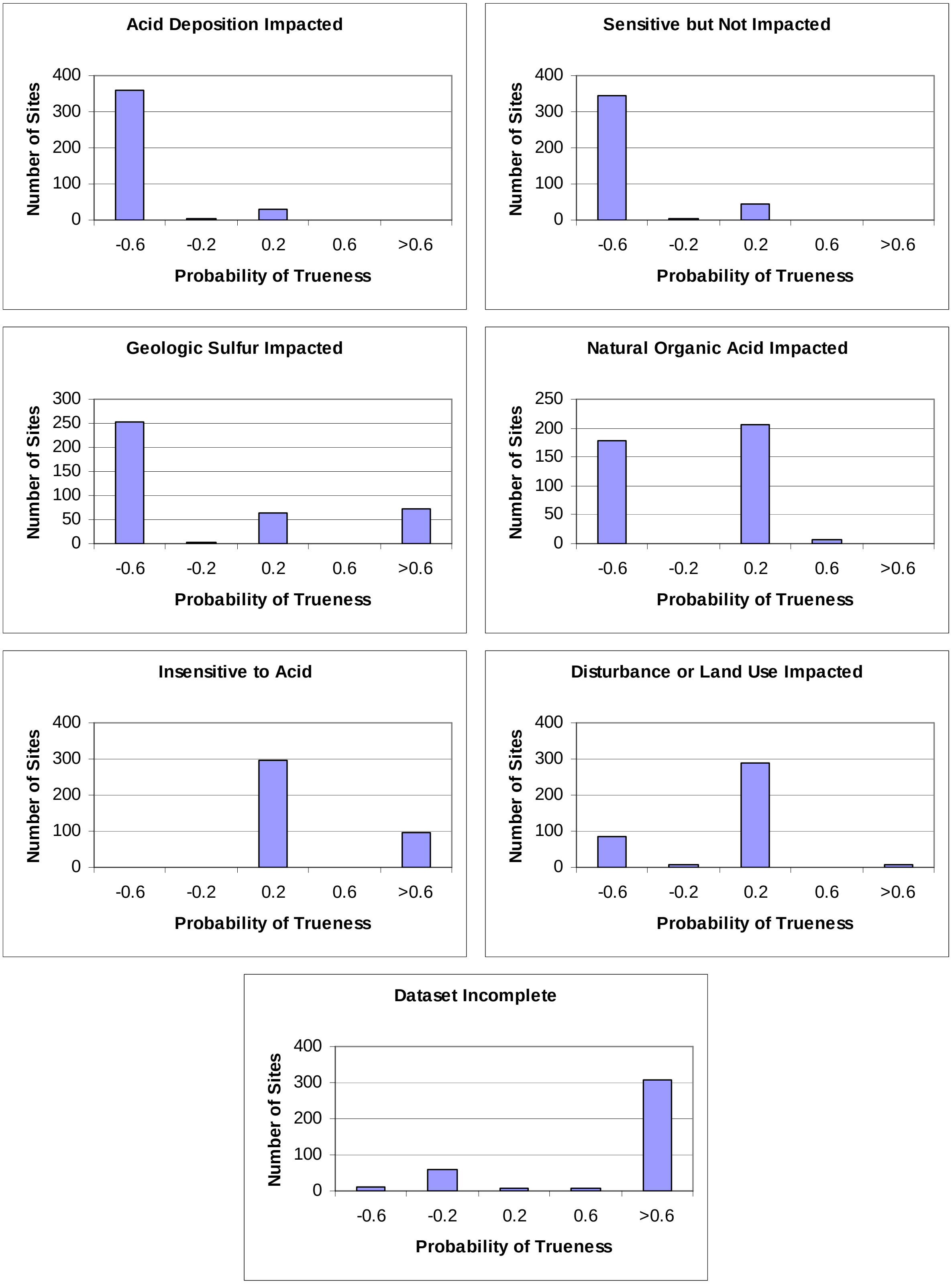


**Table 10-9: GRTE lake locations rated false in the 'Insensitive to Acid' category using extreme water chemistry values.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| GRTE0093 | Forget-Me-Not Lake | GRTE0350 | Cirque Lake |
| GRTE0106 | Pond #SD01 | GRTE0353 | Pond #MO23 |
| GRTE0129 | Pond #ND12 | GRTE0355 | Pond #MO24 |
| GRTE0131 | Pond #ND11 | GRTE0361 | Pond #MO01 |
| GRTE0137 | Timberline Lake | GRTE0368 | Pond #MO21 |
| GRTE0168 | Bradley Lake | GRTE0408 | Dudley Lake |
| GRTE0180 | Pond# SC01 | GRTE0449 | Pond #NS14 |
| GRTE0188 | Iceflow Lake | GRTE0450 | Pond #NS13 |
| GRTE0198 | Surprise Lake | GRTE0454 | Pond #WB30 |
| GRTE0205 | Amphitheater Lake | GRTE0461 | Pond #WB02 |
| GRTE0301 | Pond #PB20 | GRTE0476 | Pond #WB22 |
| GRTE0308 | Lake Solitude | GRTE0479 | Pond #WB21 |
| GRTE0315 | Pond #LE22 | GRTE0483 | Pond #WB10 |

The DSS found two lakes, Jackson Lake near Dam (GRTE0387) and Jackson Lake (GRTE0519), possibly to be impacted by disturbance or land use. Nitrate levels at these two locations were above 14 μeq/L. The DSS did not make an assessment for 111 lakes. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

### *Streams - Average Water Chemistry Values*

Table 10-10 lists the results of the Synthesis DSS for average water chemistry values at streams in Grand Teton NP and Figure 10-5 represents this data graphically.

**Table 10-10: DSS Results for Average Stream Values - GRTE**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 360 | 346 | 253 | 178 | 0 | 87 | 10 |
| -0.59 to -0.20 | 4 | 2 | 2 | 1 | 0 | 9 | 59 |
| -0.19 to 0.20 | 28 | 43 | 64 | 207 | 296 | 289 | 6 |
| 0.21 to 0.60 | 0 | 1 | 0 | 6 | 0 | 1 | 8 |
| 0.61 to 1.00 | 0 | 0 | 73 | 0 | 96 | 6 | 309 |

Of the 364 streams for which the DSS made an assessment about acid deposition, all of them are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category). Many of these streams have high ANC (> 150 μeq/L), specific conductance (> 20 μS/cm), and base cation concentrations (> 200 μeq/L) values. None of the streams were identified as being acid deposition impacted (true in the 'Acid Deposition Impacted' category).

The DSS identified 348 stream locations that are classified as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These streams have high ANC and specific conductance values, and high base cation concentrations.

Only 1 stream was found to be sensitive but not impacted (true in the 'Sensitive but Unimpacted' category): Grassy Creek at Grassy Lake Outlet (GRTE0643). This location had moderate buffering capabilities, but low nitrate and sulfur concentrations.

The DSS considered 255 of the stream locations to not show acid affects from geologic sulfur (false in the 'Geologic Sulfur Impacted' category). This is mainly attributable to the substantial buffer capacity of these lakes. The few sites that have sulfate values indicate concentrations commonly are very low (< 5 μeq/L). Table 10-11 lists the 73 stream locations that were found to show acidic effects from geologic sulfur (true in the 'Geologic Sulfur Impacted' category). These locations have moderate to high sulfate concentrations, but have neutral or slightly basic pH (≥ 7).

**Table 10-11: GRTE stream locations rated true in the 'Geologic Sulfur Impacted' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| GRTE0002 | Spring Creek | GRTE0279 | Spread Creek above Skull Creek |
| GRTE0003 | Spring Creek at Highway 22 | GRTE0297 | Unnamed Spring near Moose Head Ranch |
| GRTE0008 | Flat Creek at US Highway 26 | GRTE0303 | Spread Creek |
| GRTE0009 | Flat Creek | GRTE0319 | Leigh Lake Outlet |
| GRTE0011 | Snake River | GRTE0329 | Snake River above Spread Creek |
| GRTE0017 | Flat Creek near National Fish Hatchery | GRTE0363 | Buffalo Fork above Lava Creek |
| GRTE0018 | Nowlin Creek at confluence of Flat Creek | GRTE0365 | Bearpaw Creek at Jackson Lake |
| GRTE0022 | Flat Creek | GRTE0370 | Lava Creek above U.S. Highway 26-287 |
| GRTE0026 | Warm Spring at Warm Spring Ranch | GRTE0373 | Jackson Lake West of Dam |
| GRTE0034 | Flat Creek | GRTE0381 | Pacific Creek |
| GRTE0036 | Gros Ventre River | GRTE0388 | Snake River |
| GRTE0037 | Gros Ventre River | GRTE0389 | Spring Creek near Jackson Lake Dam |
| GRTE0043 | Flat Creek | GRTE0390 | Snake River below Jackson Lake Dam |
| GRTE0045 | Flat Creek | GRTE0394 | Moran Creek; above Jackson Lake |
| GRTE0052 | Alkali Creek | GRTE0399 | Pilgrim Creek at Jackson Lake |
| GRTE0054 | 42-117-24BAD | GRTE0400 | Third Creek at Jackson Lake |
| GRTE0056 | Lake Creek near Teton Village, | GRTE0416 | North Moran Creek above Jackson Lake |
| GRTE0057 | Granite Creek near Teton Village | GRTE0499 | Pilgrim Creek |
| GRTE0059 | Gros Ventre River | GRTE0513 | Pilgrim Creek |
| GRTE0067 | Gros Ventre | GRTE0523 | Colter Canyon Creek at Jackson Lake |
| GRTE0069 | Warm Spring | GRTE0538 | Arizona Creek at Jackson Lake |
| GRTE0072 | Gros Ventre at Outlet of Lower Slide Lake | GRTE0539 | Arizona Creek |
| GRTE0081 | Kelly Warm Spring | GRTE0548 | Moose Creek at Jackson Lake |
| GRTE0083 | Stewart Draw | GRTE0549 | Berry Creek; above Jackson Lake |
| GRTE0094 | Snake River | GRTE0554 | Lizard Creek near Lizard Point |
| GRTE0099 | 43-116-35BBC | GRTE0578 | Snake River at Jackson Lake |

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| GRTE0100 | Snake River | GRTE0611 | Snake River above Jackson Lake |
| GRTE0109 | Ditch Creek | GRTE0612 | Snake River above Jackson Lake |
| GRTE0111 | Snake River | GRTE0620 | Sheffield Creek |
| GRTE0116 | Blacktail Ponds at Outlet | GRTE0623 | Snake River at Flagg Ranch Bridge |
| GRTE0128 | Ditch Creek below South Fork | GRTE0624 | Snake River |
| GRTE0146 | Taggart Creek | GRTE0632 | Polecat Creek |
| GRTE0209 | Cottonwood Creek above Glacier Gulch | GRTE0634 | Polecat Creek |
| GRTE0215 | Snake River near Upper Schwabacker Landing | GRTE0660 | Lewis River at Mouth |
| GRTE0234 | Cottonwood Creek at Outlet of Jenny Lake | GRTE0662 | Snake River above Lewis River |
| GRTE0239 | Teton Creek | GRTE0665 | Lewis River near Mouth |
| GRTE0253 | Cascade Creek near Jenny Lake | | |

At 179 streams, the DSS found the locations to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted' category). This is due to high buffer capacity as represented by high ANC values, high specific conductance values, and high concentrations of base cations. Six streams were found to be impacted by natural organic acids (true in the 'Natural Organic Acid Impacted' Category): L12352 (GRTE0103), Ditch Creek (GRTE0115), L12184 (GRTE0304), L12186 (GRTE0369), M45188 (GRTE0633), and M44567 (GRTE0635).

The DSS identified 96 streams as insensitive to acid (true in the 'Insensitive to Acid' category). These streams would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (>100 μeq/L) and high specific conductance values (≥ 20 μmhos/cm). None of the streams were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category). The DSS did not make an assessment for 296 streams. This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category.

Only 96 streams were found to not suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). In most of these cases, the nitrate concentration was ≤ 10 μeq/L. Seven locations were found possibly to be impacted by acid due to disturbance or land use practices (true in the 'Disturbance or Land Use Impacted' category): Lower Cache Creek (GRTE0005), Flat Creek (GRTE0006), Jackson NFH Flat Creek (GRTE0031), Jackson NFH Flat Creek (GRTE0032), Jackson NFH Flat Creek (GRTE0035), Blacktail Ponds at Outlet (GRTE0116), and Snake River above Jackson Lake (GRTE0612). The nitrate concentration at these locations is 16 μeq/L. The DSS did not make an assessment for 289 streams. This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS evaluates all of the locations in terms of the completeness of the input data. Sixty-nine locations containing five, six, or all seven inputs have complete datasets. The other 323 lake locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Streams - Extreme Water Chemistry Values*

Table 10-12 contains the results of the Synthesis DSS of extreme water chemistry value for streams in GRTE. Figure 10-6 includes graphs of the data in this table.

**Table 10-12: DSS Results for Extreme Stream Values - GRTE**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 357 | 340 | 251 | 172 | 1 | 82 | 11 |
| -0.59 to -0.20 | 5 | 5 | 4 | 1 | 1 | 6 | 57 |
| -0.19 to 0.20 | 29 | 45 | 65 | 213 | 296 | 289 | 7 |
| 0.21 to 0.60 | 1 | 2 | 0 | 6 | 0 | 6 | 8 |
| 0.61 to 1.00 | 0 | 0 | 72 | 0 | 94 | 9 | 309 |

Of the 363 streams for which the DSS made an assessment about acid deposition, 362 of them are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category). Many of these streams have high ANC (> 150 μeq/L), specific conductance (> 20 μS/cm), and base cation concentrations (> 200 μeq/L) values. One stream, South Fork of Avalanche Canyon (GRTE0154), was identified as being acid deposition impacted (true in the 'Acid Deposition Impacted' category). Its low buffering capacity was indicated by a low ANC (20 μeq/L).

The DSS identified 345 stream locations that are classified as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These streams have high ANC and specific conductance values, and high base cation concentrations. Only 2 streams were found to be sensitive but not impacted (true in the 'Sensitive but Unimpacted' category): South Fork of Avalanche Canyon (GRTE0154) and Grassy Creek at Grassy Lake Outlet (GRTE0643). These locations had moderate buffering capabilities, but low nitrate and sulfur concentrations.

The DSS considered 255 of the stream locations to not show acid effects from geologic sulfur (false in the 'Geologic Sulfur Impacted' category). This is mainly attributable to the substantial buffer capacity of these lakes. The few sites that have sulfate values indicate concentrations are low (< 20 μeq/L). Seventy-two locations that were found to show acidic effects from geologic sulfur (true in the 'Geologic Sulfur Impacted' category). These locations have moderate to high sulfate concentrations, but have neutral or slightly basic pH (≥ 7). These locations are listed in Table 10-11, with Ditch Creek below South Fork (GRTE0128) removed from this list.

At 173 streams, the DSS found the locations to be not impacted by natural organic acid (false in the ‘Natural Organic Acid Impacted’ category). This is due to high buffer capacity as represented by high ANC values, high specific conductance values, and high concentrations of base cations. Six streams were found possibly to be impacted by natural organic acids (true in the ‘Natural Organic Acid Impacted’ Category): L12352 (GRTE0103), Ditch Creek (GRTE0115), L12184 (GRTE0304), L12186 (GRTE0369), M45188 (GRTE0633), and M44567 (GRTE0635).

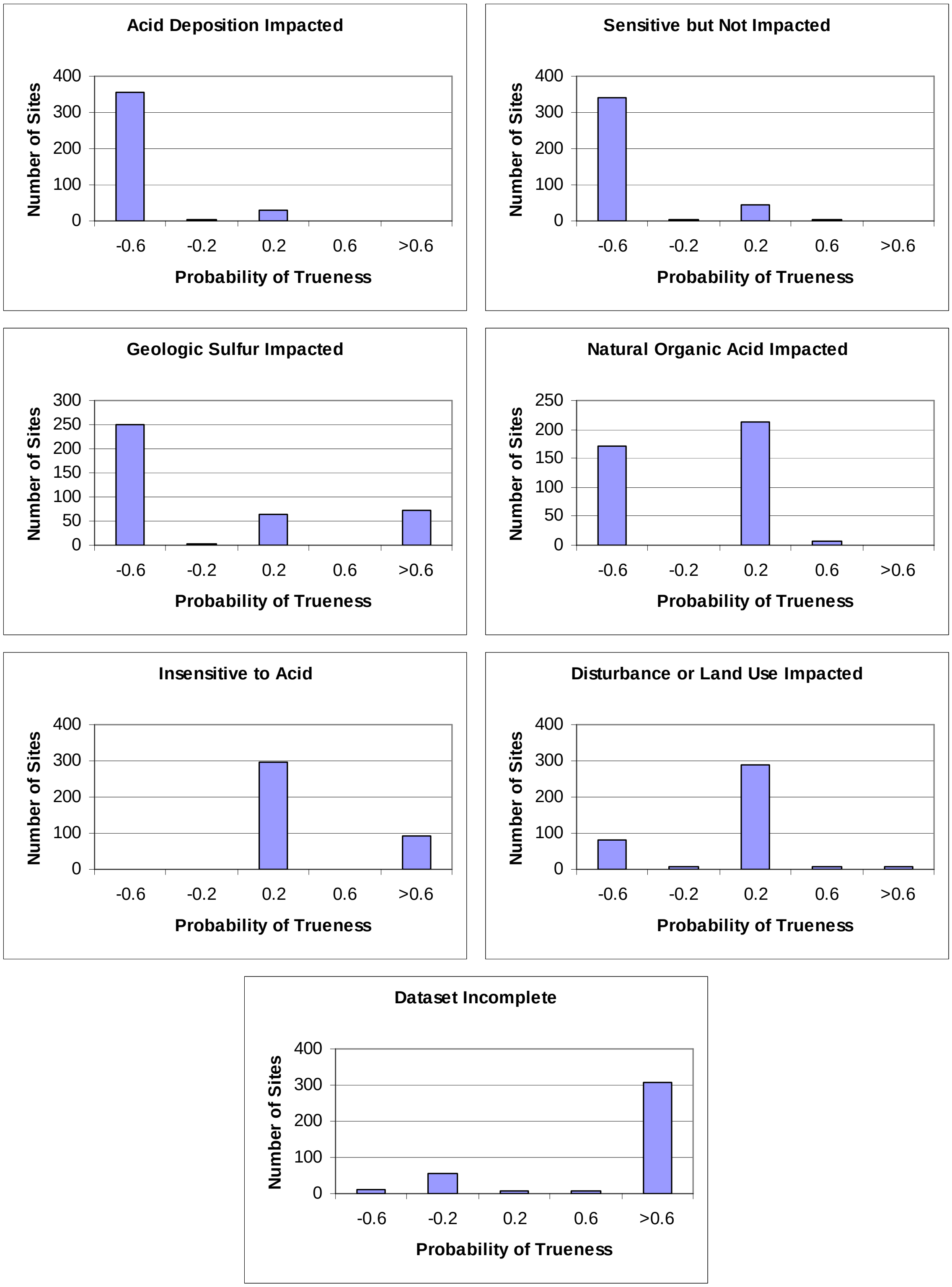
The DSS identified 94 streams as insensitive to acid (true in the ‘Insensitive to Acid’ category). These streams would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These streams have high ANC values (>100 μeq/L) and high specific conductance values (≥ 20 μmhos/cm). Two of the streams, South Fork of Avalanche Canyon (GRTE0154) and Garnett Canyon Creek (GRTE0183), were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the ‘Insensitive to Acid’ category). The DSS did not make an assessment for 296 streams. This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category.

Only 88 streams were found to not suffer from the results of disturbance or land use (false in the ‘Disturbance or Land Use Impacted’ category). In most of these cases, the nitrate concentration was ≤ 10 μeq/L. The 15 locations found possibly to be impacted by acid due to disturbance or land use practices (true in the ‘Disturbance or Land Use Impacted’ category) are listed in Table 10-13. The nitrate concentration at these locations is greater than 15 μeq/L. The DSS did not make an assessment for 289 streams. This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category.

**Table 10-13: GRTE stream locations rated true in the ‘Disturbance or Land Use’ category using extreme water chemistry values.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| GRTE0005 | Lower Cache Creek | GRTE0388 | Snake River near Moran |
| GRTE0006 | Flat Creek North of Jackson | GRTE0487 | Waterfalls Canyon Creek at Jackson Lake |
| GRTE0028 | Jackson NFH Flat Creek | GRTE0507 | Falcon Creek at Jackson Lake |
| GRTE0031 | Jackson NFH Flat Creek | GRTE0509 | Falcon Creek at Jackson Lake |
| GRTE0032 | Jackson NFH Flat Creek | GRTE0522 | Colter Canyon Creek at Jackson Lake |
| GRTE0033 | Jackson NFH Flat Creek | GRTE0524 | Colter Canyon Creek at Jackson Lake |
| GRTE0035 | Jackson NFH Flat Creek | GRTE0612 | Snake River above Jackson Lake |
| GRTE0116 | Blacktail Ponds | | |

**Figure 10-6: Charts of DSS Results for Extreme Stream Values - GRTE**



## Conclusion

The sampling in Grand Teton NP seems to be fairly extensive compared to many parks. Samples cover a range of several decades and include numerous samples collected as recently as the 1990's. Few samples included analysis for DOC, nitrate, or sulfate, however, and limit the ability of the DSS to address potential problems related to natural organic acids, land use disturbance, or geologic sulfur. ANC data indicate most lakes to be well-buffered, but a small number of lakes to be only minimally buffered and, thus, potentially sensitive to acidic deposition.

DSS results agree with prior studies that acid deposition impacts do not seem to have occurred. Additionally, DSS results indicate a small number of lakes potentially sensitive to acid deposition but most lakes to be insensitive. DSS results indicate the greatest potential problems in lakes to be caused by geologic sulfur, in spite of the paucity of data on sulfate concentrations. The DSS tended to not make conclusions regarding disturbance or land use impacts, because of the lack of data on nitrate concentrations, but did conclude that one lake likely was so impacted.

DSS results for streams are similar to those for lakes, with the greatest potential for problems to be from geologic sulfur. Some potential for impact from disturbance or land use and from natural organic acids was concluded for a small number of the stream samples.

# Chapter 11 - Rocky Mountain National Park

## Background

### Description

Rocky Mountain National Park (ROMO) was created in 1915. It straddles the Continental Divide in the northern Front Range of the Colorado Rocky Mountains. ROMO is 108,200 ha in area, with approximately 93% of the park in existing or proposed wilderness.

The park has an extensive boundary of 235 km, of which 61% is contiguous with national forest and 39% with private lands. Metropolitan and agricultural areas along the eastern edge of the Colorado Front Range are important source areas for atmospheric pollutants that may impact the park. The largest city is Denver, 60 km to the southeast, but other potential urban source areas include Boulder, Longmont, Loveland and Fort Collins. Additional sources include the Yampa Valley west of the park and cattle feed lots to the east in Greeley.

The hydrologic cycle of high-elevation watersheds in ROMO is characterized by a lengthy period of snowpack accumulation during autumn, winter, and early spring, followed by a snowmelt period during late spring and early summer. In late summer and early fall, runoff is predominantly baseflow, with some snowmelt continuing and some stormflow from precipitation events (Campbell et al. 1995).

The predominant direction of air mass movement over the Front Range is from west to east (Barry 1973), with periodic upslope movement from the east and southeast (Kelley and Stedman 1980). Wind rose data from ROMO during the period 1989 through 1995 showed a distinct pattern of predominant air movement from the northwest; there is greater variation in ROMO than suggested by data from the meteorological tower due to topographic variation. However, a second frequent wind direction was from the south and southeast, from the general direction of the Denver metropolitan area. This is important because air masses that move directly from the Denver area to ROMO have the potential to transport high levels of nitrogen and sulfur to the park. The easterly upslope storm track also carries air masses across agricultural (livestock and fertilized cropland) and industrial/metropolitan areas of Colorado before reaching the vicinity of ROMO (Bowman 1992). Higher atmospheric concentrations of ammonia, $NO_X$ gases, and nitric acid particulates have been measured near the park during upslope events (Parrish et al. 1986, Langford and Fehsenfeld 1992).

## Deposition

ROMO lies in the Front Range of the Colorado portion of the Rocky Mountains 60 km northwest of the Denver-Boulder urban areas and 30 km west of Fort Collins. The proximity to large urban areas makes the park vulnerable to pollution from both point and mobile sources (including more dispersed sources such as livestock feedlots). Over half of the total $SO_2$ emissions for the state are generated within this 140 km range. Coal-burning power plants are the major emission sources of $SO_2$ and $NO_X$ in this region. The high proportion of automobile commuters and large number of suburban residents contribute to $NO_x$ and VOC production in the region. Agricultural activities likely contribute to the regional emissions of $NH_3$. $NO_X$ and $NH_3$ emissions from adjacent counties that are upwind during parts of the year pose a potential threat to ROMO and surrounding wildland areas.

Annual inorganic N loading in wet deposition in the Colorado Front Range is about twice that of the Pacific states and is similar to some states in the Northeast (Williams et al. 1996a). Nitrate concentrations in the snowpack at maximum snowpack accumulation in the northern Colorado Front Range were among the highest measured in Colorado (Turk et al. 1992). Concentrations of $NO_3^-$ and $SO_4^{2-}$ in the snowpack along the Continental Divide in northern Colorado were found to be twice the regional background level found throughout the Rocky Mountains in 1991 and 1992 (Turk et al. 1992).

ROMO has a high-elevation NADP/NTN site located in the Loch Vale watershed at an elevation of 3,159 m and a lower elevation site at Beaver Meadows (2,490 m). Both sites receive precipitation with elevated levels of S and N, compared with western parks in general.

Wet S deposition at Loch Vale decreased from 3.1 kg S/ha/yr in 1985 to values around 2 kg S/ha/yr during the period 1987 though 1995 (Figure 11-1). The pattern of sulfur loss in discharge (which can provide some information about inputs) was similar to the yearly water discharge pattern during the past decade, with most sulfur losses occurring during snowmelt. Total sulfur losses from the Loch Vale basin were considerably higher than wet inputs, and ranged from 3.3 to 4.2 kg S/ha/yr (Baron et al. 1995). This information, coupled with discovery of small pyrite deposits within the basin, suggests a significant mineral source of S in the Loch Vale basin (Mast et al. 1990). Interpretation of potential ecosystem effects of decreased sulfur emissions and deposition since 1984 is obscured by the apparent internal watershed sources of sulfur (Baron et al. 1995). Wet N deposition at Loch Vale during the period 1983 through 1995 has generally been in the range of 2 to 3 kg N/ha/yr, with a maximum of 3.9 kg N/ha/yr in 1994 (Figure 11-2). There has been no trend in seasonal or annual inputs (Baron et al. 1995). Greater wet inputs of N occurred during years with higher precipitation, particularly those years with higher precipitation during winter. N deposition was statistically correlated with patterns of precipitation using a Pearson product-moment correlation ($p > 0.01$). Wet deposition at Beaver Meadows is considerably lower than at Loch Vale for both S and N (Figures 11-3 and 11-4).

**Figure 11-1: Sulfate wet deposition at Loch Vale NADP site in ROMO from 1983-2003.**

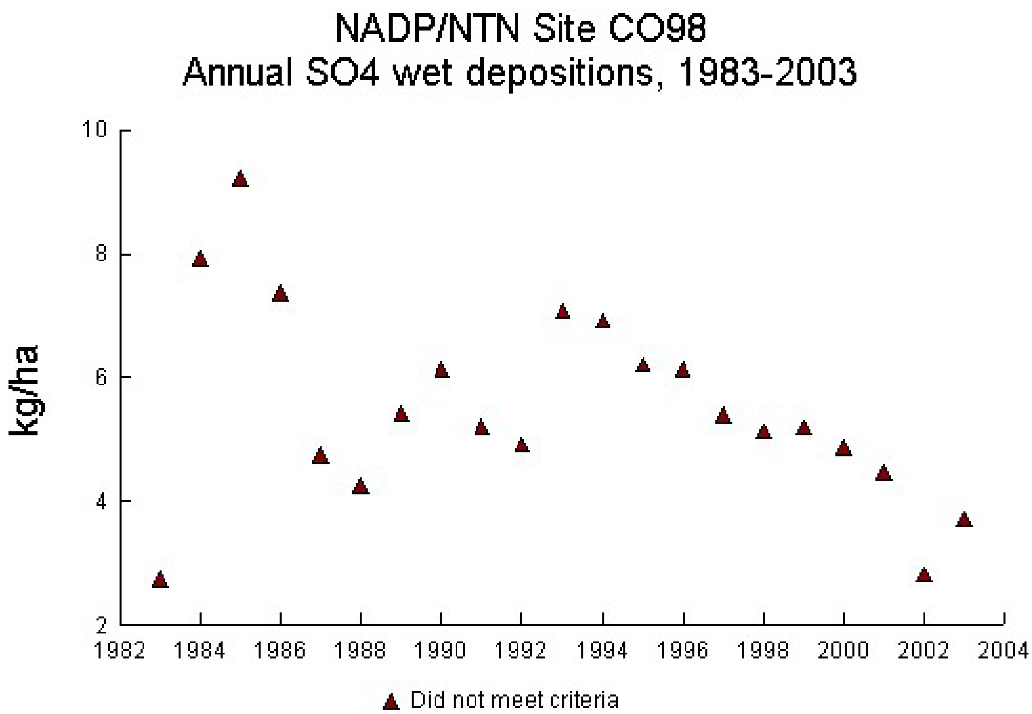



**Figure 11-2: Inorganic N wet deposition at Loch Vale NADP site in ROMO from 1983-2003.**

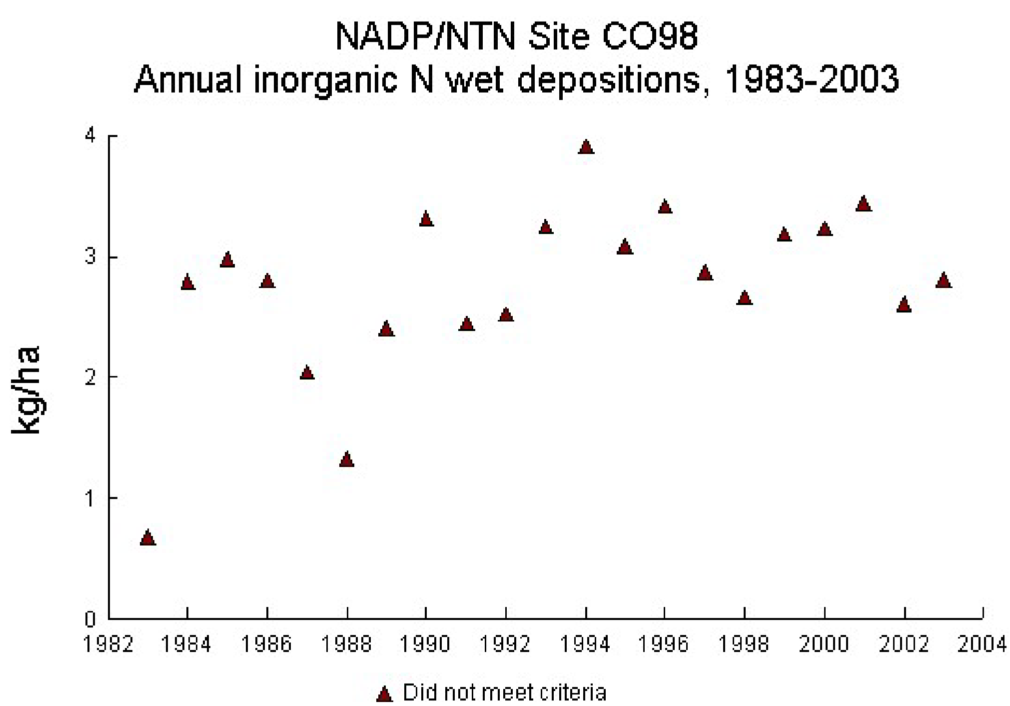


**Figure 11-3: Sulfate wet deposition at Beaver Meadow NADP site in ROMO from 1983-2003.**

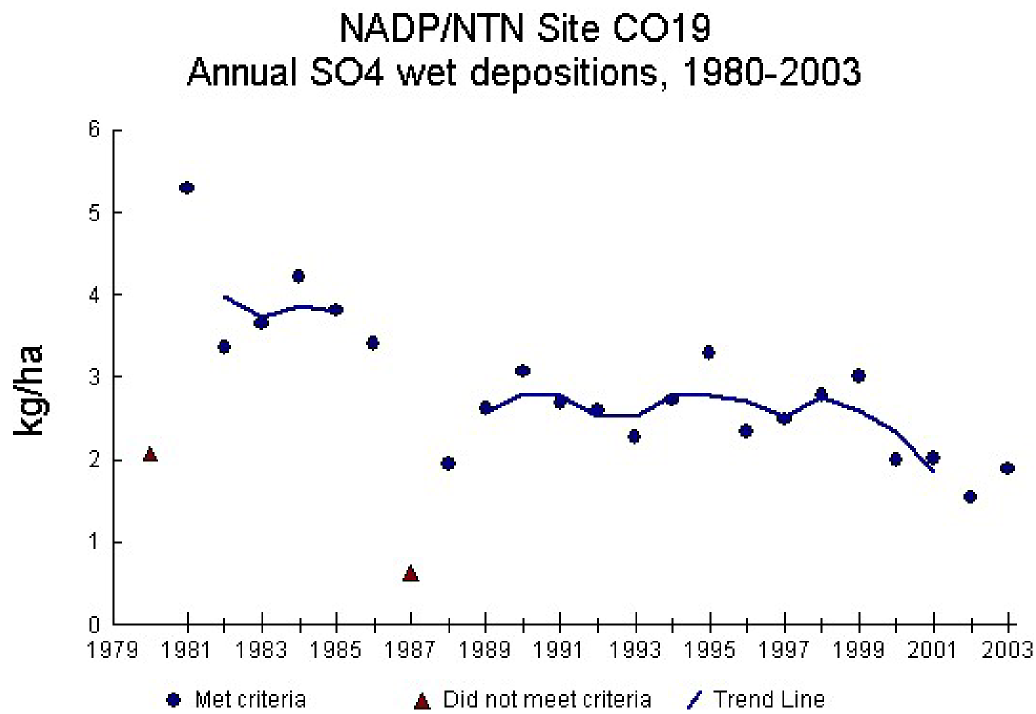
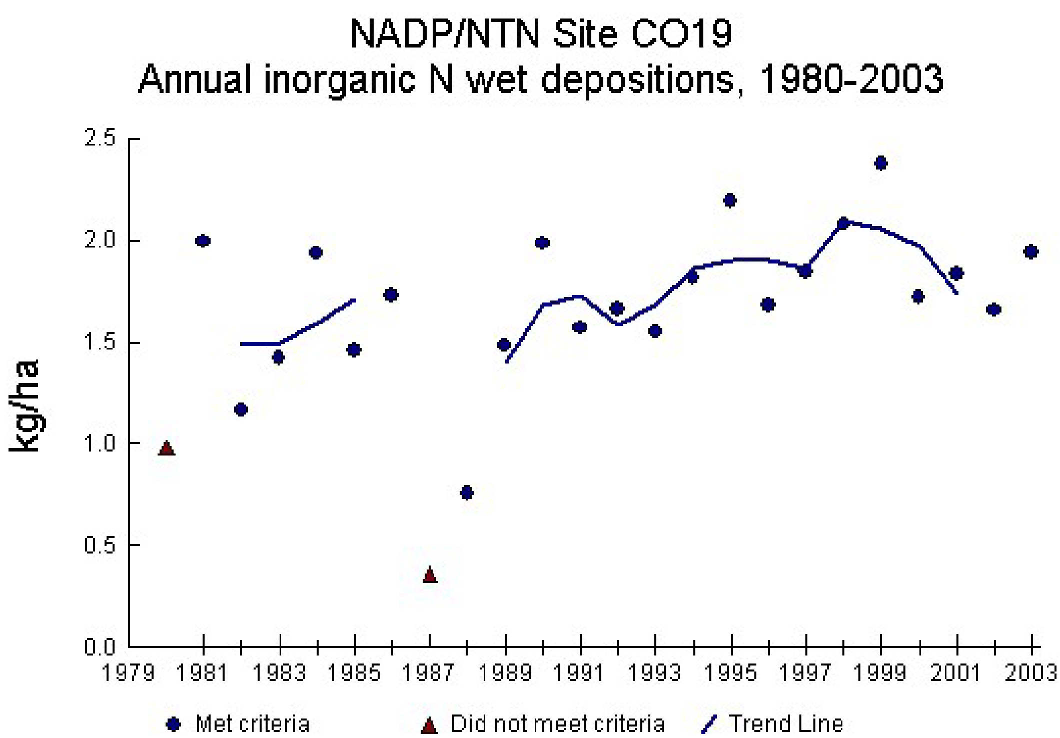



**Figure 11-4: Inorganic N wet deposition at Beaver Meadow NADP in ROMO from 1983-2003.**



Annual loading of inorganic N in wet deposition to the Colorado Front Range is about 3 kg N/ha/yr at Loch Vale and near 5 kg N/ha/yr at Niwot Ridge, which is quite high for the western United States, although still relatively modest by comparison with many areas of the eastern United States and Europe. Annual $NO_3^-$-N loading at Niwot Ridge, an alpine research area south of ROMO, has approximately doubled over the last decade, from 2 to 4 kg $NO_3^-$ N/ha/yr, based on NADP data. An increase in precipitation amount during that period of time explained about half of the observed variation in annual wet $NO_3^-$ deposition (Williams et al. 1996a).

Whereas dry deposition in the Rocky Mountains contributes less than 25% of total deposition of most chemical species (with the exception of $Ca^{2+}$) in winter, based on measurements from the maximum snowpack accumulation, the contribution of dry deposition in summer is uncertain. A comparison of the chemical composition of lakes and wetfall suggested no significant dry deposition of $SO_4^{2-}$ to sensitive high elevation lakes in the Rocky Mountains (Turk and Spahr 1991).

The scientific consensus is that dry deposition of sulfur at ROMO is not a major component of total deposition, and that the observed high concentrations of $SO_4^{2-}$ in streamwater at Loch Vale are due largely to the occurrence of sulfide-bearing minerals in the watershed (Campbell et al. 1995; J. Baron, pers. comm.). Dry deposition to exposed bedrock surfaces appears to be important, however, at least during the snow-free season. Volume-weighted concentrations of $NO_3^-$ and $SO_4^{2-}$ in runoff from a bedrock catchment at Loch Vale were two to four times higher than in precipitation (Clow and Mast 1995). About 15% of the solute increase could be accounted for by evaporation from the rock surface. However, it is unclear to what extent runoff $NO_3^-$ concentrations were increased by N-fixation of lichens or the extent of sulfur contribution from mineral deposits in the bedrock. Thus, the data of Clow and Mast (1995) cannot be used to quantify dry deposition fluxes to this watershed.

Studies conducted by Langford and Fehsenfeld (1992) at Niwot Ridge and also 25 km to the east, near the eastern edge of the forest at Boulder, illustrated that the forest canopy will act as both a source and a sink for atmospheric $NH_3$. During periods of westerly flow (low in $NH_3$), the forest acted as a source of $NH_3$ with mean $NH_3$ emission rates of about 1.2 ng/m$^2$/sec. Periods of easterly (upslope) flow induced by insulation of the mountain surfaces often occur between mid-morning and late afternoon during the summer. During these periods, the forest (especially the eastern edge) is exposed to $NH_3^-$enriched air masses from the agricultural plains to the east. During upslope conditions, the forest became a net sink for $NH_3$, with a mean uptake rate of about 10 ng/m$^2$/sec (20 °C) near Boulder and decreasing from east to west, as $NH_3$ was depleted from the air masses.

Ratios of $NO_3^-$ to $SO_4^{2-}$ in wetfall (0.8) and bulk precipitation (1.1) were high at Loch Vale compared to other mountainous sites in the region (Arthur and Fahey 1993). This may be due to the interception by Loch Vale and surrounding areas of southeasterly and easterly winds from the Denver area and agricultural areas east of the park, which are enriched in nitrogen compounds.

Sulfur dioxide has been measured in ROMO since 1991, and annual average 24-hr concentrations range from 0.04 to 0.09 ppbv. In 1993, the maximum 24-hour $SO_2$ concentration in the park was 0.42 ppbv. These values are much lower than the concentration that is considered potentially damaging to some vegetation (Treshow and Anderson 1989). Maximum 24-hr $SO_2$ concentrations measured at ROMO in 1995 (0.13 ppbv) are only one-third of the 1993 level (0.42 ppbv; Table 14). However, it is important to remember that a maximum value may be an anomaly. Mean values are a better representation of typical conditions.

## Water Quality

Aquatic resources in ROMO include a wealth of lakes and streams of exceptional quality. The natural lakes and stream valleys were formed by glaciation. The majority of the surface waters in the park are found in alpine and subalpine settings, most of which are accessible only on foot or horseback. Many high-elevation surface waters are fed by small glaciers. Because of the proximity of so many ROMO surface waters to the Continental Divide, human impacts on the water quality are minimized. With the exception of anthropogenic atmospheric contributions of pollutants, human impacts on most lakes and streams in the park, especially those in remote locations, are restricted to a few dams and irrigation channels, as well as the impacts of hiking, camping, and horseback-riding activities. Atmospheric deposition of air pollutants therefore represents one of the most important potential threats to aquatic resources in this park.

Lakes and streams in ROMO tend to be clear-water, low ionic strength, oligotrophic systems. Concentrations of virtually all dissolved constituents except oxygen (e.g., nutrients, organic material, major ions, weathering products) tend to be very low. ROMO surface waters can be categorized as clear, cold, dilute systems that are highly sensitive to degradation by human activities.

Water quality in the park can be adversely impacted by atmospheric deposition of nitrogen or sulfur. Sulfur deposition can cause chronic and/or episodic acidification of surface waters. Nitrogen deposition can cause acidification, eutrophication, and excessive algal productivity. Common water quality measurements to determine the status of water quality AQRVs include pH, ANC, and concentrations of $SO_4^{2-}$, and $NO_3^-$.

Although chronic acidification of surface waters is not currently a problem in the Rocky Mountain region (Turk and Spahr 1991), episodic acidification during snowmelt may be occurring at some sites and is an important concern. In addition, because many lakes and streams in the region have low ANC, there is concern about potential chronic acidification if levels of atmospheric deposition of N or S increase in the future.

A wide range of sulfate concentrations illustrates the importance of watershed sources of S to many lakes in the area, because concentrations would be more similar (smaller range of values) if atmospheric deposition was the primary source (e.g., Turk and Spahr 1991).

A lake and stream sampling program was conducted by the U.S. Fish and Wildlife Service in four large watersheds of ROMO (Figure 6; Gibson et al. 1983). The study watersheds included the East Inlet and Upper Colorado River basins on the west side of the Continental Divide, and the Glacier Gorge and Fall River basins on the east side of the Divide. Water samples were collected under base flow conditions, i.e., sampling did not occur within 24 hours after rainstorms. Lake samples were collected at each inlet, outlet, and lake-center location. Stream samples were collected 25 m below each confluence and at 150 m elevation intervals. The lakes and streams were generally low in ionic strength.

Four of the eight study subbasins had average alkalinity values less than 50 μeq/L and two had average alkalinity between 50 and 100 μeq/L, suggesting widespread sensitivity to acidic deposition effects. Each had average pH values in the range of 6.0 to 6.9. Two subbasins (Upper Fall River and Upper Colorado River) had relatively high alkalinity (180 and 332 μeq/L, respectively) and pH (7.1 and 7.5) and we consider them to be insensitive to acidification effects. Alkalinity, base cation concentrations, and silica were all found to be inversely related to elevation in the subbasins with homogeneous mineralogy and low alkalinities (Glacier Creek, Loch Vale, Ypsilon Creek, Roaring River, and East Inlet; Gibson et al. 1983). However, using probability-sampling results from the Western Lakes Survey, Eilers et al. (1988) found little or no relationship between ANC and lake elevation.

The acid-base chemistry of lake and stream waters in ROMO is primarily a function of the interactions among several key parameters and associated processes: atmospheric deposition, bedrock geology, the depth and composition of surficial deposits and associated hydrologic flowpaths, and the occurrence of soils, tundra, and forest vegetation. High concentrations of base cations, alkalinity, and silica occur in the upper Colorado River basin, an area underlain by highly weatherable ash flow tuff and andesite. In contrast, the alkalinity and base cation concentrations are much lower in Glacier Creek, a watershed underlain by Silver Plume granite (Gibson et al. 1983).

The study basins and subbasins were ranked in terms of their presumed sensitivity to acidification on the basis of cation concentrations and pH of stream and lake water samples collected in the study areas. The three subbasins that comprise the Glacier Gorge basin (Loch Vale, Glacier Creek, and Tyndall Gorge) and one of the subbasins (Ypsilon Lake Subbasin) within the Fall River basin were consistently ranked by Gibson et al. (1983) as most sensitive to potential effects of acidic deposition. These were the four subbasins with surface waters lowest in pH and base cation concentrations of the subbasins studied. Three of them (Tyndall Gorge, Loch Vale, and Ypsilon Lake) received a large percentage of their drainage water from snowmelt during summer.

Peak concentrations of nutrients and DOC in surface waters occurred at the beginning of the snowmelt. This indicates that soil solution is flushed into surface water at that time. After the initial flushing, the ionic strength of surface water decreases throughout the melting period due to the dilution of soilwater with the large contribution of meltwater (Denning et al. 1991). The decline in ANC in surface waters is caused by several things, including dilution of base cation concentrations by meltwater, increase in organic acid anions, and increase in $NO_3^-$ concentrations.

Dissolved organic carbon (DOC) concentrations, indicative of organic acidity, are extremely low in most acid-sensitive waters in ROMO. DOC and organic acid anion concentrations are always low in these sensitive aquatic systems. With respect to our evaluation of potential atmospheric impacts, natural organic acidity is of less importance than in many acid-sensitive regions elsewhere.

A great deal of research has been conducted on the interactions between atmospheric pollutants and water quality at the Loch Vale watershed. Biogeochemical and hydrological processes have been studied intensively at this site since 1983 (e.g., Baron 1992, Denning et al. 1991, Campbell et al. 1995, Baron and Campbell 1997). A general description of the watershed is as follows. Loch Vale watershed is a 7-$km^2$ basin situated along the Continental Divide in the southeastern portion of ROMO. Fifty-five percent of the surface area is exposed bedrock. Twenty-six percent is talus, where large boulders are interspersed with tundra underlain by thin, minimally-developed Entisol soils (Walthall 1985). Alpine tundra covers 11% of the watershed, and the remainder is glaciers and lakes (2%), well-developed subalpine forest soils (5%), and alluvial and bog soils located in saturated areas and adjacent to streams (1%) (Walthall 1985, Baron and Campbell 1997).

A number of factors predispose watersheds in ROMO such as Loch Vale to potential adverse effects of nitrogen deposition. These include:

- Steep watershed gradient
- Short hydrologic residence time of lakewaters
- Large input of N to lakes and streams during the early phases of snowmelt
- High percentage of watershed covered by exposed bedrock and talus; small percentage of watershed covered by forest
- Phosphorus limitation of aquatic ecosystem primary production in some surface waters.

Thus, it is not surprising that the Loch Vale watershed leaches relatively high amounts of $NO_3^-$ under only moderate levels of N deposition. In order to understand the response of this watershed (and other similar watersheds in the park) to atmospheric N deposition, it is important to consider a variety of hydrologic and biogeochemical processes that occur in different parts of the basin. These are described in general terms below.

The Loch Vale watershed can, for all practical purposes, be considered nitrogen-saturated (e.g., Aber et al. 1989, Stoddard 1994). It is not clear to what extent the terrestrial and aquatic systems are receiving N inputs in excess of the assimilative capacities of watershed biota, however. The apparent N-saturation may be entirely hydrologically-mediated. In other words, hydrologic flowpaths and brief soil water residence times may limit the opportunity for biological uptake to the extent that the ecosystems may be N-limited but still be unable to utilize atmospheric inputs of N (Campbell et al. 1995). Nevertheless, the implications of this apparent N-saturation are important with respect to the estimation of critical loads of N deposition (Williams et al. 1996a). For example, critical loads for N deposition have been estimated to be 10 kg N/ha/yr for northern Europe, based on empirical results that showed little or no N leaching to surface waters below this level (Dise and Wright 1995). Clearly, leaching of $NO_3^-$ to surface waters occurs at much lower levels of N deposition at ROMO and probably at other areas of the Front Range.

During the last 10 years, the annual minimum concentrations of $NO_3^-$ in surface waters during the growing season have increased from below detection limits to about 10 μeq/L in high-elevation catchments at Niwot Ridge and in GLEES in southeastern Wyoming (Williams et al. 1996b). Wet $NO_3^-$ deposition to adjacent NADP collectors has more or less doubled during that time period at both sites.

Tundra areas had significantly lower $NO_3^-$ concentrations than talus and bedrock areas, suggesting that tundra ecosystems are still N-limited and that nitrification combined with limited plant uptake account for the high concentrations of $NO_3^-$ observed in waters draining talus and bedrock areas (Williams et al. 1996b).

Much of the water that flows into lakes and streams in ROMO first passes through a portion of the watershed and makes contact with soils, talus or exposed bedrock. Interactions between runoff water and these surfaces modify the runoff water chemistry. Soil solution data from Loch Vale illustrate the differences in N uptake and mobility with landscape type. In view of such high concentrations of $NO_3^-$ in drainage from talus fields, Campbell et al. (1996) concluded that the source of much of the inorganic N in surface waters of Loch Vale is likely shallow groundwater that flows through talus. This high-N source mixes with water that has lower concentrations of N, resulting in streamwater with peak $NO_3^-$ concentrations of about 40 μeq/L and that remain above 10 μeq/L throughout the growing season (Campbell et al. 1996). Thus, the sensitivity of alpine and subalpine lakes and streams in ROMO is strongly influenced by the upslope topography.

The greatest threat from air pollution to aquatic resources in ROMO is nitrogen deposition and consequent lake and stream acidification (Peterson et al. 1998). Both, chronic and especially episodic acidification (loss of ANC) have probably already occurred in some acid-sensitive park waters. However, the magnitude of acidification likely has been small and it has probably not had a significant impact on aquatic biota. There is no evidence that any surface waters in the park have become chronically acidic as a consequence of nitrogen deposition. However, the aquatic resources in portions of ROMO are considered to be at great risk to adverse impacts of atmospheric nitrogen. Continued systematic monitoring of deposition and water quality should be considered high priority activities.

Because of the documented poor N retention capacity of many alpine watersheds in ROMO, we expect that any increase in the atmospheric N load will result in increased concentrations of $NO_3^-$ in alpine and subalpine lakes and streams. If such changes are sufficiently large, surface water acidification, particularly episodic acidification, of aquatic ecosystems will likely occur.

Effects of atmospheric deposition on water chemistry in ROMO are reasonably well understood. N deposition likely is causing elevated concentrations of $NO_3^-$ in surface waters in many watersheds within and outside the park on the east side of the Continental Divide. These elevated $NO_3^-$ concentrations have most likely resulted in decreased alkalinity of lakes and streamwaters, although it does not appear that any surface waters in the park are acidic (ANC 0) as a consequence. Because some watersheds are already leaching relatively high levels of $NO_3^-$ under current deposition, that further increases in atmospheric N loading probablly will cause increased leaching of $NO_3^-$ from exposed bedrock areas and talus slopes (where vegetative and microbial uptake is limited) in high-elevation watersheds and perhaps increased leaching from tundra and subalpine forest soils. It has not been demonstrated that soils in the park have become N-saturated, however.

Loch Vale watershed is more vulnerable to atmospheric inputs of N than to inputs of S (Baron et al. 1995). Due to the probable internal watershed sources of S and the observed lack of response of streamwater $SO_4^{2-}$ concentration to recent changes in sulfur deposition, Baron et al. (1995) concluded that the Loch Vale watershed is unresponsive to the levels of S deposition observed within the Rocky Mountains over the last 10 years. In contrast, concentrations of $NO_3^-$ in surface waters in Loch Vale are relatively high, are likely controlled largely by atmospheric inputs of nitrogen, and will increase if deposition increases in the future. Thus, nitrogen in the form of nitrogen deposition is the primary air pollutant concern with respect to aquatic resources throughout the park.

## Aquatic Chemistry Data and DSS Results

### Horizon Report

The Horizon report was released for Rocky Mountain NP in October 2001. The report contains information on 684 water bodies in the park. More water bodies exist, but were not sampled. 87% of water bodies in the report contained data relevant to the DSS. The report details 202 lakes, 439 streams, and 43 springs in Rocky Mountain NP. Table 11-1 lists the number of sites that have data for each DSS component. The numbers indicate that data for all waters is moderately complete.

**Table 11-1: Chemistry Component Summary - ROMO**

| | Total | Lakes | Streams | Springs |
|---|---|---|---|---|
| Number | 684 | 202 | 439 | 43 |
| Conductance | 472 | 153 | 300 | 19 |
| pH | 473 | 133 | 305 | 35 |
| ANC | 295 | 94 | 190 | 11 |
| DOC | 89 | 55 | 34 | 0 |
| Nitrate | 388 | 118 | 232 | 38 |
| Base Cations | 320 | 100 | 190 | 30 |
| Sulfate | 324 | 95 | 198 | 31 |

Lakes and streams had similar numbers of data elements used by the DSS. 24% of stream sites and 29% of lake sites had zero or one data elements used by the DSS, while 31% of stream sites and 32% of lake sites and had six or all seven of these data elements. This highlights the need for a standard set of chemical analyses to be performed on any water samples taken in the park.

**Table 11-2: Number of Elements Summary - ROMO**

| # of Elements | Total | Lakes | Streams | Springs |
|---|---|---|---|---|
| 0 | 92 | 17 | 74 | 1 |
| 1 | 71 | 41 | 30 | 0 |
| 2 | 136 | 18 | 109 | 9 |
| 3 | 55 | 20 | 33 | 2 |
| 4 | 54 | 14 | 19 | 21 |
| 5 | 70 | 27 | 39 | 4 |
| 6 | 155 | 35 | 114 | 6 |
| 7 | 51 | 30 | 21 | 0 |

Of the 675 sites that had any data collection, including parameters not used by the DSS, 5 sites were last sampled in the 1950s, 36 in the 1960s, 176 in the 1970s, 265 in the 1980s, and 193 in the 1990s. The lake data, on average, was newer than the stream data, with 46% of lakes last sampled during the 1980s and 37% in the 1990s. In contrast, 34% of streams were last sampled in the 1970s. Some of the data in this report is 15 years old or older and may not indicate current water chemistry conditions. Compared to other parks in the study, the data at Rocky Mountain NP is reasonably up to date. However, additional sampling should take place so that the DSS can have up to date data for making recommendations.

Of the 295 locations that had alkalinity data, sampling occurred only once at 54% of them. At these locations, the mean and extreme ANC values are the same. Alkalinity results were based on more than 10 samples at 16% of all locations. More frequent future sampling will aide in gaining a more robust data set for entry into the DSS.

## ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

### *Mean ANC*

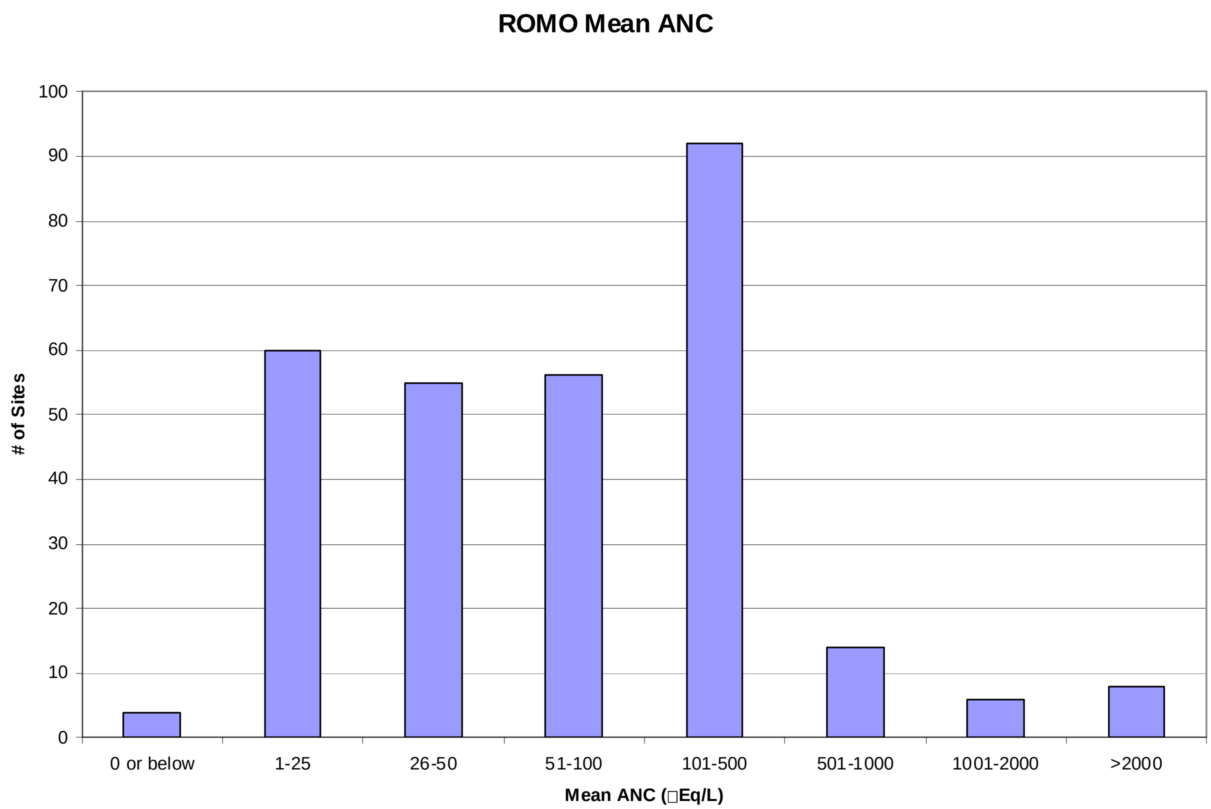
Of the 295 sampling locations which contained data for ANC calculations, 40% had a mean ANC below 50 μeq/L, 22% had means below 25 μeq/L, and 4 had means less than or equal to 0 μeq/L. These four locations are listed in Table 11-3.

**Table 11-3: Locations with mean ANC less than 50 μeq/L - ROMO**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| ROMO0105 | Lake Verna at Rocky Point near Outlet | 0.0 |
| ROMO0175 | Boulder Brook Main Stem Headwater 1 | -2.3 |
| ROMO0177 | Boulder Brook Main Stem Headwater 2 | -3.5 |
| ROMO0189 | Boulder Brook Main Stem at Trail Crossing in Boulder Field | -4.4 |

Figure 11-5 contains a graph of the frequency distribution of mean ANC values in Rocky Mountain NP.

**Figure 11-5: Frequency Distribution of Mean ANC Values - ROMO**




*Minimum ANC*

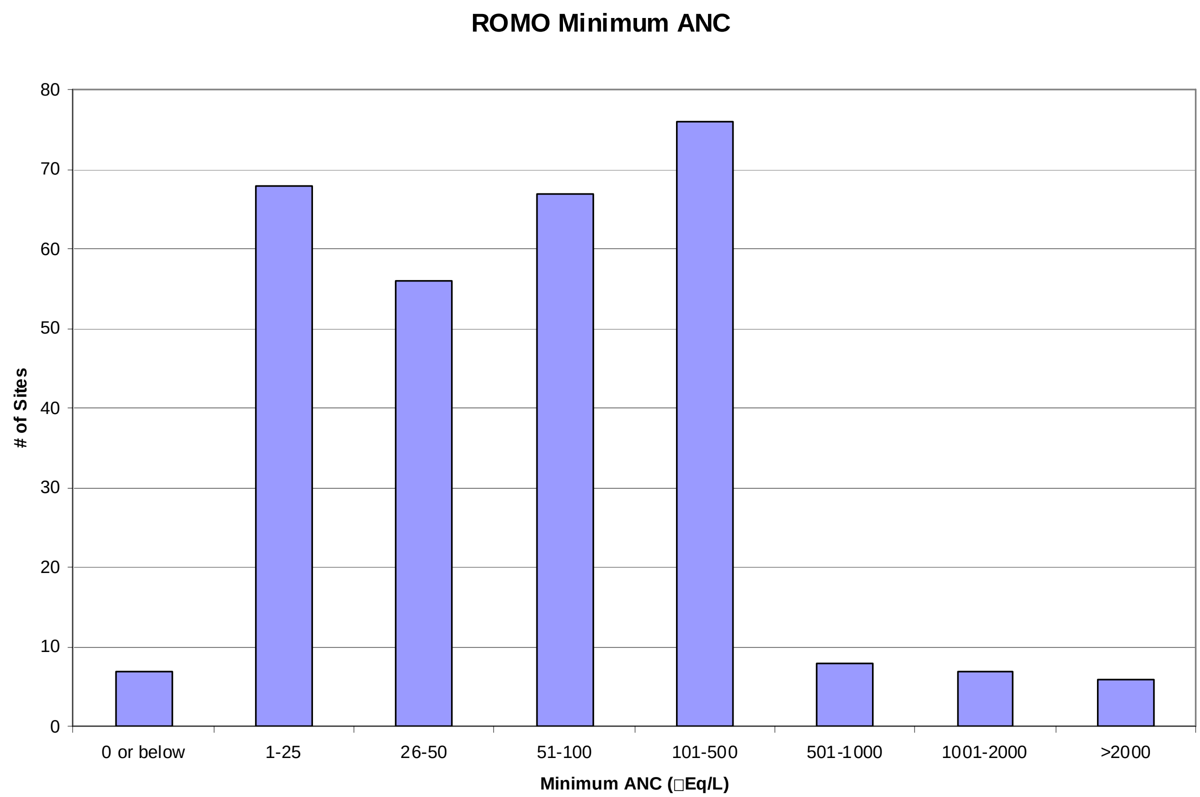
Of the 295 sampling locations which contained data for ANC calculations, 44% had mean ANCs below 50 μeq/L, 25% had means below 25 μeq/L, and 7 had means less than or equal to 0 μeq/L. These locations appear in Table 11-4.

**Table 11-4: Locations with minimum ANC less than 50 μeq/L - ROMO**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| ROMO0105 | Lake Verna at Rocky Point near Outlet | 0.0 |
| ROMO0175 | Boulder Brook Main Stem Headwater 1 | -2.3 |
| ROMO0177 | Boulder Brook Main Stem Headwater 2 | -3.5 |
| ROMO0189 | Boulder Brook Main Stem at Trail Crossing in Boulder Field | -4.4 |
| ROMO0246 | Boulder Brook Spring at 11,600 feet | -6.7 |
| ROMO0282 | Boulder Brook East Minor Stem | -12.0 |
| ROMO0339 | Boulder Brook Main Stem at 2,926 meters | -3.1 |

Figure 11-6 contains a graph of the frequency distribution of minimum ANC values in Rocky Mountain National Park.

**Figure 11-6: Frequency Distribution of Minimum ANC Values - ROMO**




## Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

### *Lakes - Average Water Chemistry Values*

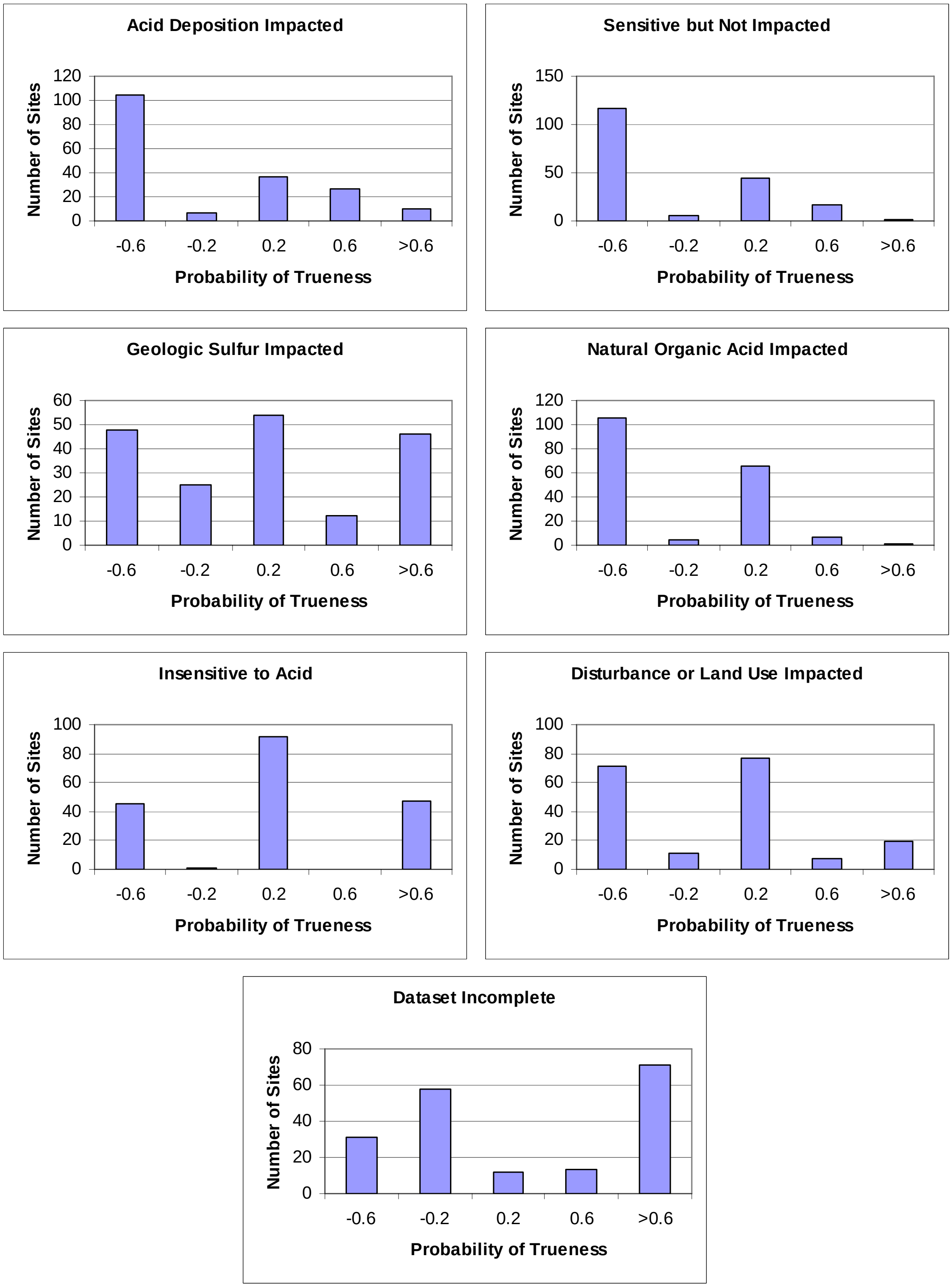
Table 11-5 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in Rocky Mountain NP and Figure 11-7 includes graphical representations of this data.

Three of the lake sites had only one data parameter for the DSS (nitrate concentration). The DSS makes recommendations with no certainty for all of the categories for these lakes except for Disturbance or Land Use Impacted.

**Table 11-5: DSS Results for Average Lake Values - ROMO**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 104 | 117 | 48 | 106 | 45 | 71 | 31 |
| -0.59 to -0.20 | 7 | 6 | 25 | 5 | 1 | 11 | 58 |
| -0.19 to 0.20 | 37 | 44 | 54 | 66 | 92 | 77 | 12 |
| 0.21 to 0.60 | 27 | 16 | 12 | 7 | 0 | 7 | 13 |
| 0.61 to 1.00 | 10 | 2 | 46 | 1 | 47 | 19 | 71 |

**Figure 11-7: Charts of DSS Results for Average Lake Values - ROMO**



*Lakes – Extreme Water Chemistry Values*

Table 11-6 lists the results of the DSS for extreme values of water chemistry parameters in lakes in Rocky Mountain NP. Figure 11-8 graphically represents these results.

**Table 11-6: DSS Results for Extreme Lake Values - ROMO**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 105 | 118 | 47 | 93 | 45 | 66 | 24 |
| -0.59 to -0.20 | 10 | 4 | 27 | 4 | 1 | 11 | 64 |
| -0.19 to 0.20 | 40 | 44 | 47 | 78 | 92 | 72 | 13 |
| 0.21 to 0.60 | 25 | 17 | 3 | 8 | 0 | 3 | 14 |
| 0.61 to 1.00 | 5 | 2 | 61 | 2 | 47 | 33 | 70 |

**Figure 11-8: Charts of DSS Results for Extreme Lake Values - ROMO**

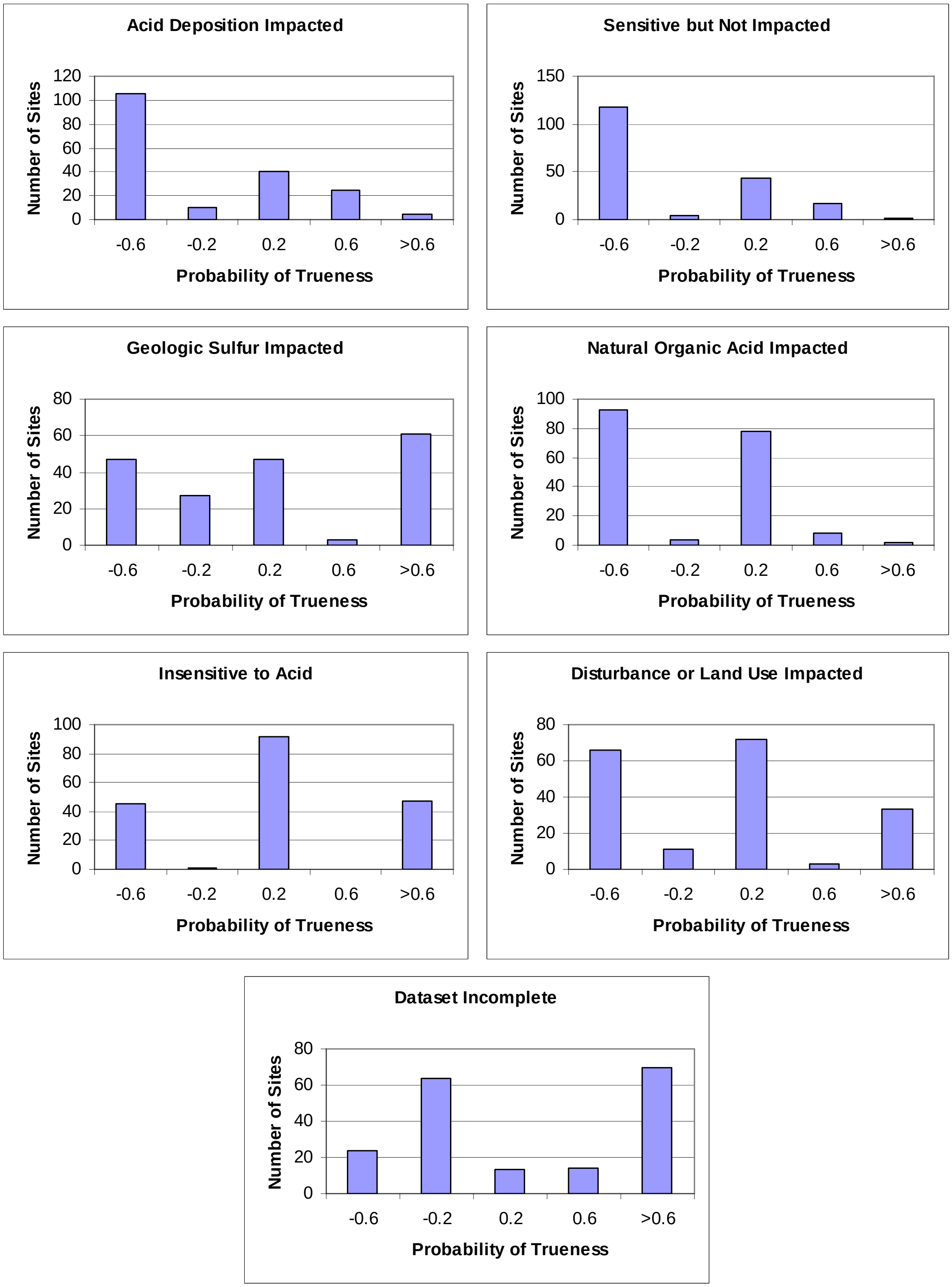
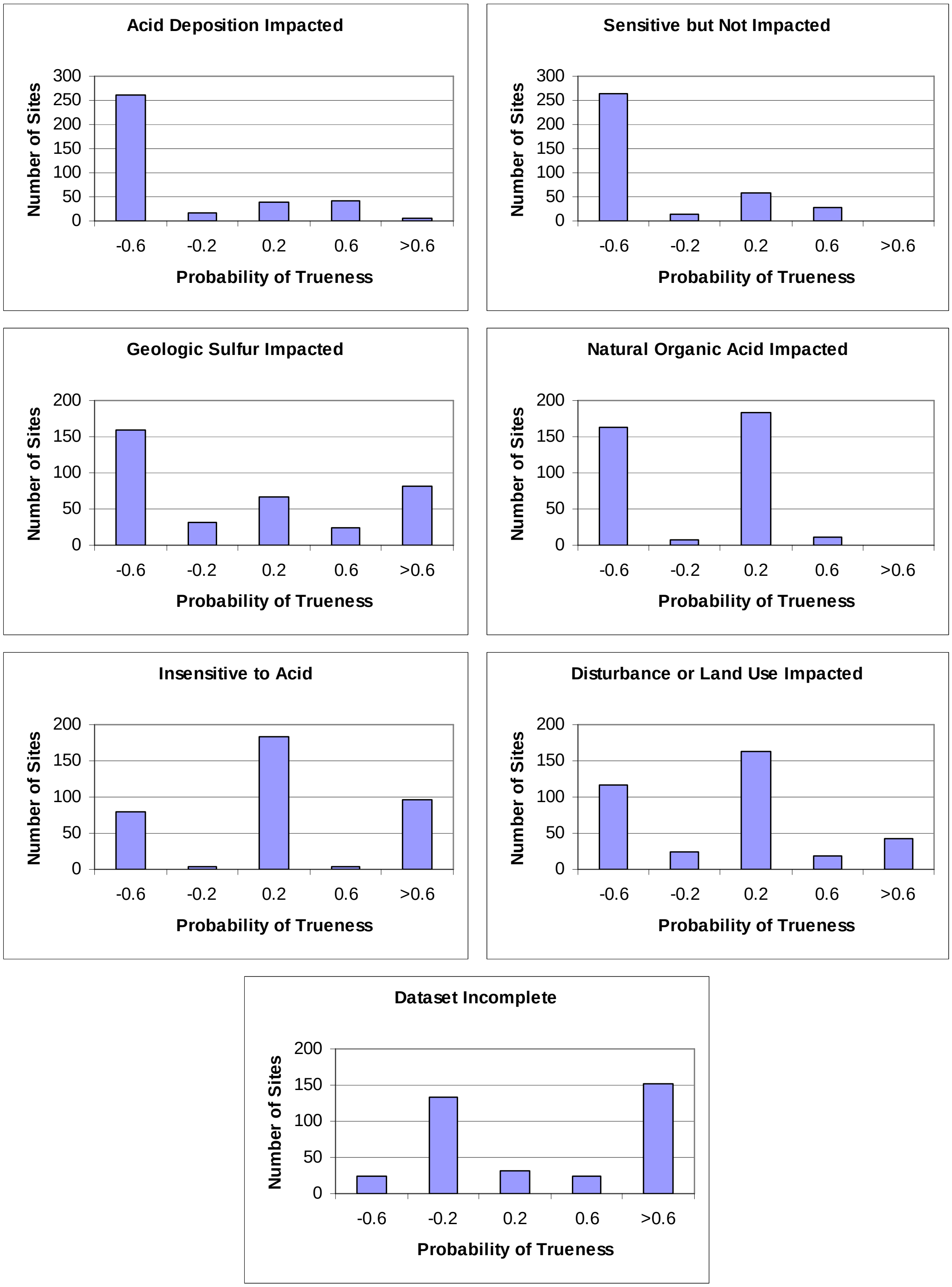


**Figure 11-9: Charts of DSS Results for Average Stream Values - ROMO**



*Streams - Average Water Chemistry Values*

Table 11-7 lists the results of the Synthesis DSS for average water chemistry values at streams in Rocky Mountain NP and Figure 11-9 represents this data graphically.

**Table 11-7: DSS Results for Average Stream Values - ROMO**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 260 | 263 | 160 | 163 | 79 | 117 | 25 |
| -0.59 to -0.20 | 18 | 14 | 32 | 7 | 3 | 24 | 134 |
| -0.19 to 0.20 | 40 | 59 | 67 | 183 | 184 | 163 | 31 |
| 0.21 to 0.60 | 41 | 29 | 25 | 12 | 3 | 19 | 24 |
| 0.61 to 1.00 | 6 | 0 | 81 | 0 | 96 | 42 | 151 |

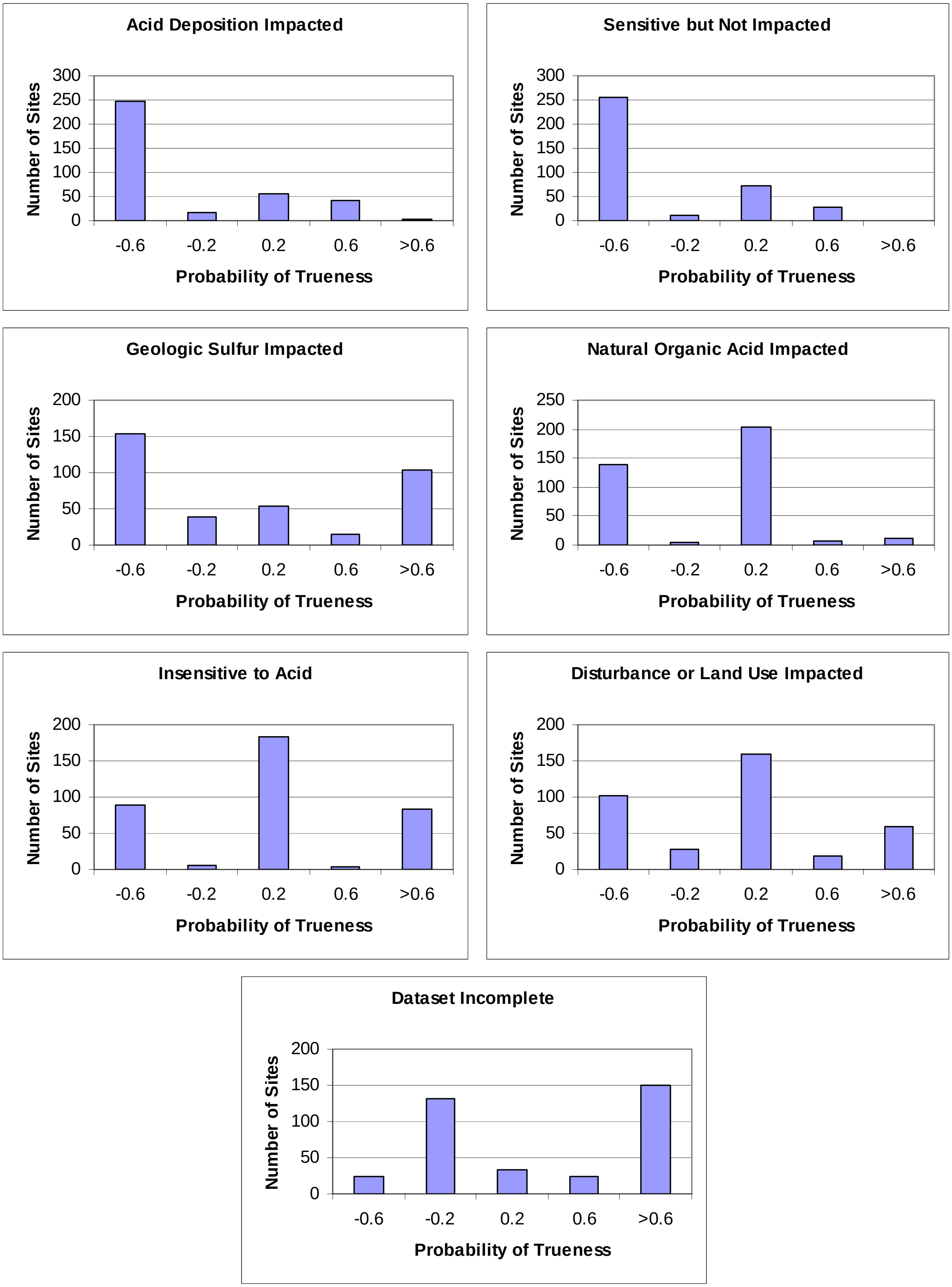
*Streams - Extreme Water Chemistry Values*

Table 11-8 contains the results of the Synthesis DSS of extreme water chemistry value for streams in Rocky Mountain NP. Figure 11-10 includes graphs of the data in this table.

**Table 11-8: DSS Results for Extreme Stream Values - ROMO**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 248 | 256 | 154 | 139 | 89 | 101 | 25 |
| -0.59 to -0.20 | 16 | 10 | 38 | 4 | 5 | 28 | 132 |
| -0.19 to 0.20 | 56 | 71 | 54 | 204 | 184 | 159 | 34 |
| 0.21 to 0.60 | 42 | 27 | 15 | 7 | 3 | 18 | 24 |
| 0.61 to 1.00 | 3 | 1 | 104 | 11 | 84 | 59 | 150 |

**Figure 11-10: Charts of DSS Results for Extreme Stream Values - ROMO**



## Analysis

The analysis was not completed for ROMO.

Data from Rocky Mountain NP were processed by the DSS, but the analysis of the DSS output was not completed due to lack of available personnel time. ANC values (Figure 11-5) indicate that a number of waterbodies in the park are potentially sensitive to acidification.

# Chapter 12 - Yellowstone National Park

## Background

### Description

Yellowstone National Park (YELL) was established as the world's first national park in 1872. Comprised of 1.1 million ha, YELL ranges in elevation from 1,600 to 3,500 m, and contains several broad volcanic plateaus, and parts of three mountain ranges: the Absaroka Mountains in the eastern, Gallatin Mountains in the northwestern, and Red Mountains in the southern portions of the park.

The high elevation of much of the park results in moderate levels of precipitation. Precipitation averages about 64 cm annually, ranging between 30 and 100 cm depending on elevation and terrain. Snowfall reaches 5 to 10 m in the Absaroka Range. Winter precipitation (November through March) contributes most to the total annual precipitation and accounts for much of the variability. Snow course records suggest that annual precipitation may exceed 200 cm on the Pitchstone Plateau near Lewis Lake. This is the only area of the park not immediately downwind (in the rain shadow) of a major mountain range (Dirks and Martner 1982).

### Deposition

YELL is located in the northwestern corner of Wyoming surrounded by Bridger-Teton, Shoshone, and Targhee National Forests and lies 10 km north of Grand Teton National Park. There is little industrial activity and low population in this portion of the state, resulting in good air quality. Most of the industrial activity in Wyoming is in the eastern counties near the cities of Gillette and Casper, and in the southwestern counties around Rock Springs. Oil and gas processing, electric utility power plants and industrial fossil-fuel combustion in southwestern Wyoming and southeastern Idaho are the major sources of gaseous pollutants in the YELL area. Annual emissions of gaseous $SO_2$, $NO_X$ and VOC are primarily from fossil-fuel combustion by industrial sources, and levels are moderate relative to other western states.

**Figure 12-1: Sulfate wet deposition at Tower Falls NADP site in Yellowstone NP from 1980-2003.**

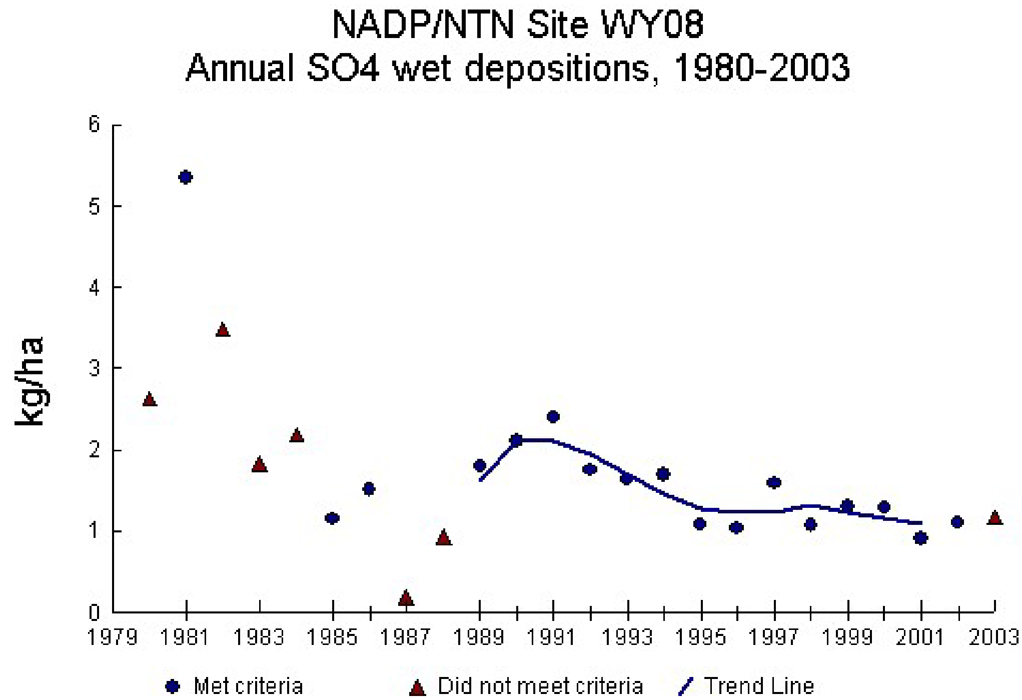
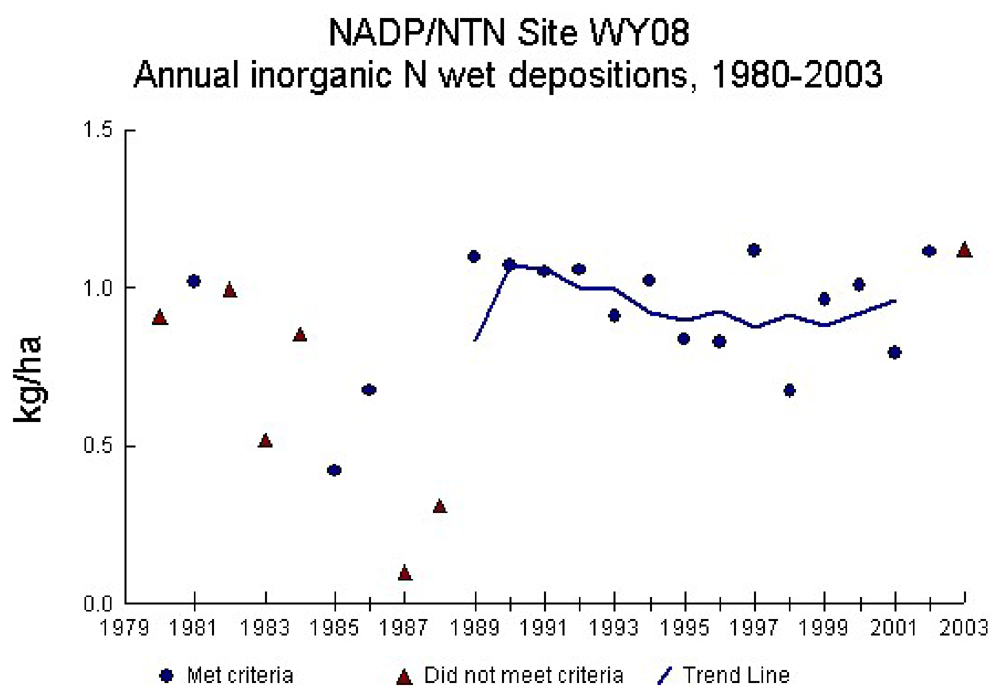



**Figure 12-2: Inorganic N wet deposition at Tower Falls NADP site in Yellowstone NP from 1980-2003.**



Precipitation volume and chemistry have been monitored at Tower Junction since 1980 by NADP/NTN. Annual precipitation amounts are generally in the range of 30 to 45 cm per year at this site. The concentration of $SO_4^{2-}$, $NO_3^-$, and $NH_4^+$ are low, with each generally below 10 μeq/L. The combined low amount of precipitation and low concentrations of acid-forming precursors results in very low levels of sulfur and nitrogen deposition. Sulfur deposition has been trending downward since 1989 and current deposition levels are typocally below 1 kg S/ha/yr (Figure 12-1). N deposition is around 1 kg/ha/yr and shows no long-term trend (Figure 12-2).

## Water Quality

YELL encompasses near-pristine watershed areas and contributes to two of the nation's farthest reaching drainages: the Missouri and Columbia Rivers. Surface water resources in the park include about 600 streams and 175 lakes. There are about 4,400 km of free-flowing rivers and streams. Four large lakes (Yellowstone, Shoshone, Lewis, and Heart Lakes) account for about 94% of the park's lake surface. The largest lake in the park is Yellowstone Lake, which is 92 m deep and 386 km$^2$ in area. Major rivers include the Yellowstone, Snake, Lewis, Madison, Gibbon, Firehole, Gardiner, and Lamar Rivers. Water quality varies throughout the park, mostly as a function of geologic terrain and the influence of thermal features. Natural geothermal discharges, which are quite common in many portions of the park, affect the pH, alkalinity, temperature, salinity, sulfate concentrations, and base cation concentrations of drainage waters. Snowmelt is an important contributor to hydrologic budgets of watersheds in the park, and water quality therefore tends to vary seasonally.

Lakes and streams in the park are, for the most part, not sensitive to acidification impacts. Base cation concentrations and ANC tend to exceed common thresholds of sensitivity. As mentioned above, deposition rates at YELL are very low, often less than 1 kg/ha/yr for both S and N. Many of the surface waters in the park receive substantial contributions of mineral acid anions from geothermal sources, amounts larger than received through atmospheric deposition.

Of 201 sites for which pH data are available, 5 had pH less than 5.5. None of these lakes or streams exhibited other data that reflected sensitivity to acidification from acidic deposition. For example, sulfate concentrations ranged from 18 mg/L to 191 mg/L in the low-pH waters, more than an order of magnitude higher than would be attributable to atmospheric deposition due to air pollution. Chloride concentrations were also high in most of these surface waters, ranging from 1 mg/L to 121 mg/L. Four of the five lakes with pH less than 5.5 had chloride concentration greater than 57 mg/L. It is likely that all of these surface waters are impacted by geothermal discharge that causes the water to be low in pH.

# Aquatic Chemistry Data and DSS Results

## Horizon Report

The Horizon report was released for Yellowstone NP in July 1994. The report contains information on 444 water bodies in the park. More water bodies exist, but were not sampled. Surface water resources in the park include about 600 streams, 57% of which were listed in the report and 175 lakes, 55% of which were covered in the report. Only 53% of water bodies in the report contained data relevant to the DSS. The report details 97 lakes, 344 streams, and 3 springs in Yellowstone NP. Table 12-1 lists the number of sites that have data for each DSS component. The numbers indicate that data for lakes, with the exception of DOC, is relatively complete, while data for streams is sparse.

**Table 12-1: Chemistry Component Summary - YELL**

| | Total | Lakes | Streams | Springs |
|---|---|---|---|---|
| Number | 444 | 97 | 344 | 3 |
| Conductance | 231 | 94 | 134 | 3 |
| pH | 229 | 96 | 130 | 3 |
| ANC | 210 | 95 | 113 | 2 |
| DOC | 27 | 8 | 18 | 1 |
| Nitrate | 222 | 96 | 124 | 2 |
| Base Cations | 216 | 96 | 118 | 2 |
| Sulfate | 221 | 96 | 123 | 2 |

Only 1% of lake sites had no data elements used by the DSS, while 60% of streams did. For those sites with data, the data is relatively complete. 97% of lake sites and 82% of stream sites with data had six or more of the data elements. With the exception of DOC, a standard set of chemical analyses were performed on water samples taken in the park.

**Table 12-2: Number of Elements Summary - YELL**

| # of Elements | Total | Lakes | Streams | Springs |
|---|---|---|---|---|
| 0 | 207 | 1 | 206 | 0 |
| 1 | 7 | 0 | 7 | 0 |
| 2 | 6 | 0 | 5 | 1 |
| 3 | 3 | 0 | 3 | 0 |
| 4 | 4 | 0 | 4 | 0 |
| 5 | 9 | 3 | 6 | 0 |
| 6 | 184 | 85 | 98 | 1 |
| 7 | 24 | 8 | 15 | 1 |

Of the 242 sites that had any data collection, including parameters not used by the DSS, 45 sites were last sampled in the 1960s, 128 in the 1970s, 51 in the 1980s, and 18 in the 1990s. All of the data was relatively dated, with 73% of lakes and 70% of streams last sampled before 1980. Only 1 lake was last sampled in the 1990s. Most of the data in this report is 15 years old or older and may not indicate current water chemistry conditions. Additional sampling should take place so that the DSS can have up to date data for making recommendations.

Of the 210 locations that had alkalinity data, sampling occurred only once at 73% of them. At these locations, the mean and extreme ANC values are the same. Alkalinity results were based on more than 10 samples at only 5% of all locations. More frequent future sampling will aide in gaining a more robust data set for entry into the DSS.

## ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

### *Mean ANC*

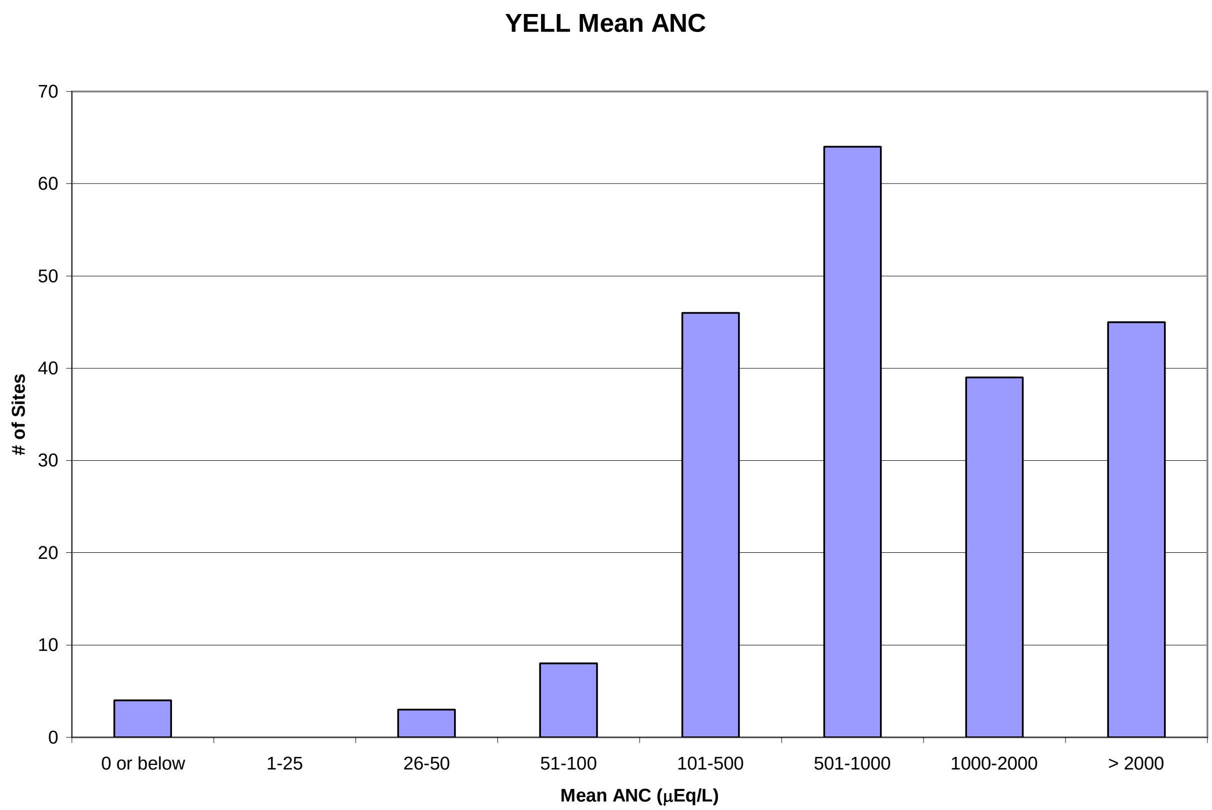
Of the 210 sampling locations which contained data for ANC calculations, 3% had a mean ANC below 50 μeq/L, including 4 that had means less than or equal to 0 μeq/L. These locations are listed in Table 12-3.

**Table 12-3: Locations with mean ANC less than 50 μeq/L - YELL**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| YELL0110 | Buffalo Lake at the base of Madison Plateau | 40 |
| YELL0136 | Unnamed tributary from Hot Springs near Old Faithful | 0 |
| YELL0192 | Astringent Creek at Mouth | 0 |
| YELL0240 | Fern Lake | -24 |
| YELL0242 | Wrangler Lake 4.8 km south of Grand Canyon at Artist Point | 40 |
| YELL0290 | Beaver Lake near Obsidian Creek | 40 |
| YELL0432 | Stillwater River at Daisy Pass #3 | 0 |

Figure 12-3 contains a graph of the frequency distribution of mean ANC values in Yellowstone NP.

**Figure 12-3: Frequency Distribution of Mean ANC Values - YELL**




*Minimum ANC*

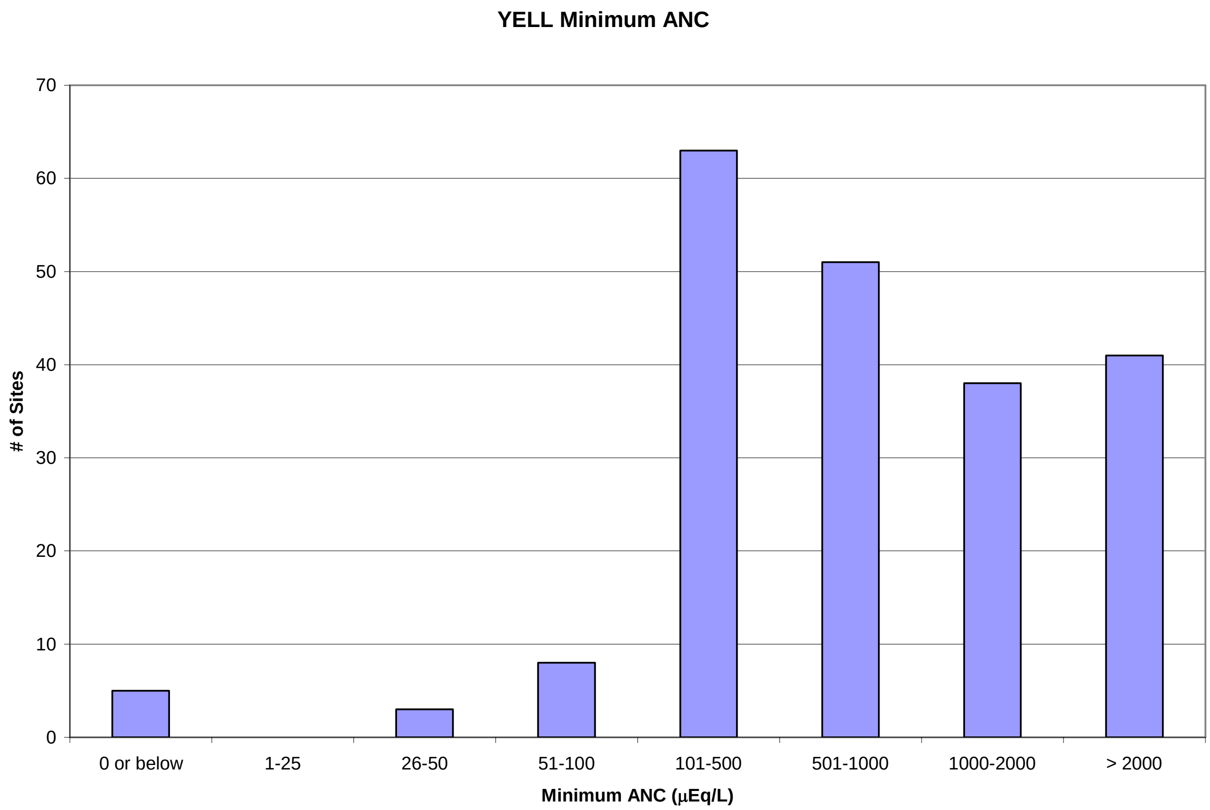
Of the 210 sampling locations which contained data for ANC calculations, 4% had minimum ANCs below 50 μeq/L, including 5 locations that had a minimum value less than or equal to 0 μeq/L. These locations are listed in Table 12-4.

**Table 12-4: Locations with minimum ANC below 50 μeq/L - YELL**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| YELL0103 | Lewis Lake 12 miles north of south entrance | 0 |
| YELL0110 | Buffalo Lake at the base of Madison Plateau | 40 |
| YELL0136 | Unnamed tributary from Hot Springs near Old Faithful | 0 |
| YELL0192 | Astringent Creek at Mouth | 0 |
| YELL0240 | Fern Lake | -24 |
| YELL0242 | Wrangler Lake 4.8 km south of Grand Canyon at Artist Point | 40 |
| YELL0290 | Beaver Lake near Obsidian Creek | 40 |
| YELL0432 | Stillwater River at Daisy Pass #3 | 0 |

Figure 12-4 contains a graph of the frequency distribution of minimum ANC values in Yellowstone NP.

**Figure 12-4: Frequency Distribution of Minimum ANC Values - YELL**




## Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

### *Lakes - Average Water Chemistry Values*

Table 12-5 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in Yellowstone N and Figure 12-5 includes graphical representations of this data.

**Table 12-5: DSS Results for Average Lake Values - YELL**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 0 | 87 | 17 | 0 | 12 | 96 | 7 |
| -0.59 to -0.20 | 0 | 2 | 1 | 0 | 0 | 0 | 86 |
| -0.19 to 0.20 | 96 | 0 | 0 | 96 | 1 | 0 | 0 |
| 0.21 to 0.60 | 0 | 7 | 13 | 0 | 2 | 0 | 0 |
| 0.61 to 1.00 | 0 | 0 | 65 | 0 | 81 | 0 | 3 |

The DSS did not make an assessment for any of the 96 lake locations concerning the 'Acid Deposition Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS identified 89 lake locations as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These lakes have high ANC (> 100 μeq/L), specific conductance values (> 40 μS/cm), and base cation concentrations (> 300 μeq/L). Seven lakes were found to be sensitive but not impacted (true in the 'Sensitive but Unimpacted' category): Grassy Lake Reservoir 100 m above Dam (YELL0004), Robinson Lake West of Bechler Ranger Station (YELL0030), Summit Lake Southwest of Bisquit Basin (YELL0133), Summit Lake Southwest of Bisquit Basin, Dryad Lake West of Yellowstone Lake (YELL0168), Mary Lake Central Plateau (YELL0194), Wrangler Lake at Artist Point (YELL0242), and Mirror Lake on Southern Mirror Plateau (YELL0267). This location had moderate buffering capabilities, but low nitrate and sulfur concentrations.

Only 18 of the lakes locations were classified as not showing acid effects from geologic sulfur (false in the 'Geologic Sulfur Impacted' category). This is mainly attributable to the substantial buffer capacity of these lakes. Sulfate concentrations in these locations are low (< 30 μeq/L). A majority of the locations, 78, were found to show acidic effects from geologic sulfur (true in the 'Geologic Sulfur Impacted' category) (Table 12-6). Many of these locations have moderate to high sulfate concentrations, but have neutral or slightly basic pH (≥ 7).

**Figure 12-5: Charts of DSS Results for Average Lake Values - YELL**

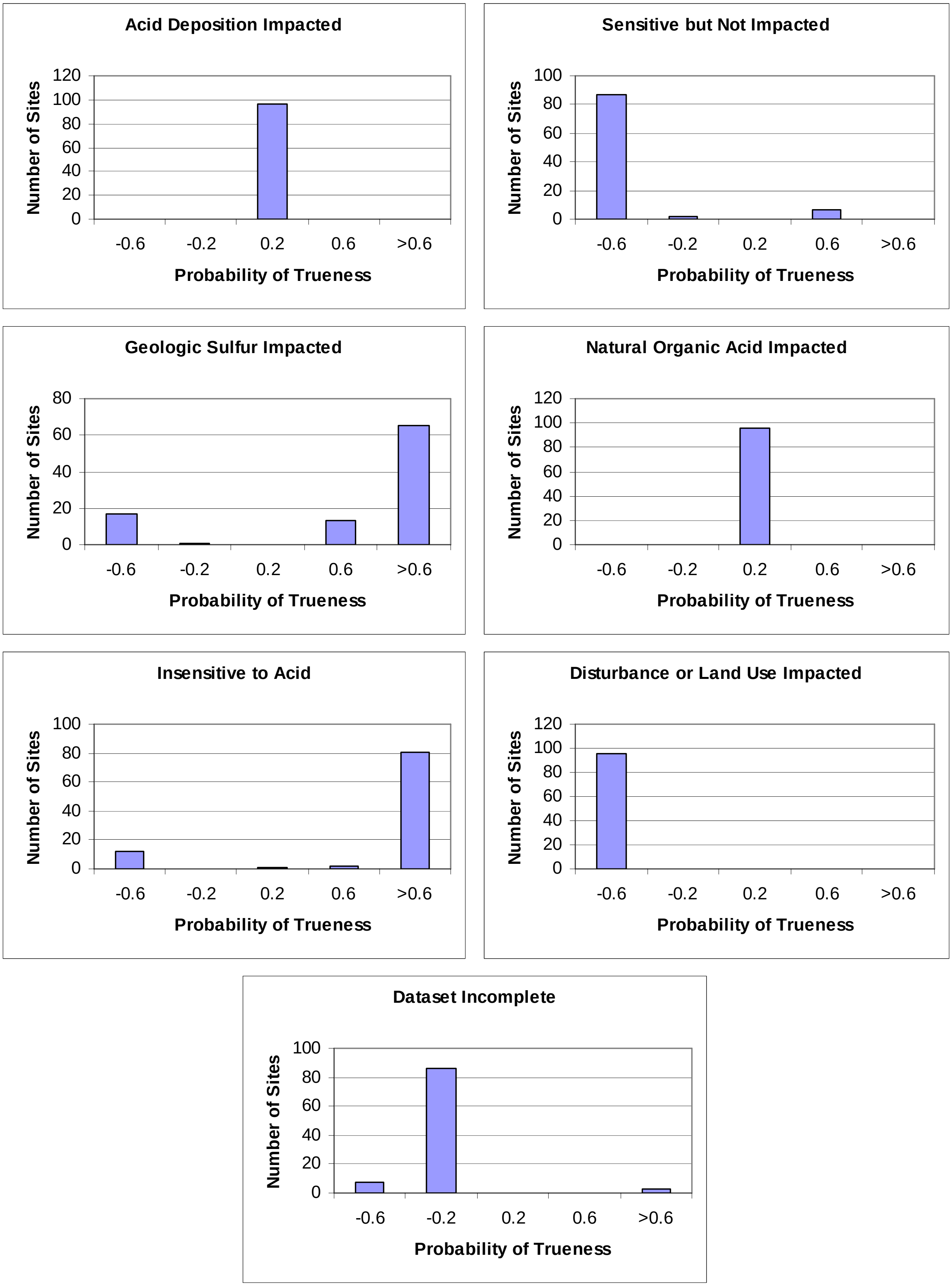


**Table 12-6: YELL lake locations rated true in the 'Geologic Sulfur Impaired' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YELL0003 | Grassy Lake Reservoir | YELL0234 | Fern Lake Northof Pelican Valley & Southwest Mirror Plateau |
| YELL0008 | Winegar Lake Falls River Basin | YELL0235 | Dewdrop Lake Northof Fishing Bridge Central |
| YELL0009 | Phoneline Lake Southwest of Bechler Ranger Station | YELL0240 | Fern Lake |
| YELL0038 | Boundary Lake#2 near Little Robinson Creek | YELL0245 | Virginia Lake Southwest on Plateau Trail |
| YELL0046 | Little Robison Lake near Bechler Ranger Station | YELL0264 | Ribbon Lake South Rim of the Grand Canyon |
| YELL0052 | Ranger Lake near Cascade Corner of Madison Plateau | YELL0270 | Cascade Lake Northeast Solfatara Plateau Central |
| YELL0054 | Wyadaho Lake at South Edge Madison Plateau | YELL0271 | Grebe Lake  Northwest of Canyon Headwaters of Gibbon |
| YELL0065 | Heart Lake South at Base of Sheridan Mountain | YELL0272 | Nymph Lake Northwest of Norris Junction |
| YELL0071 | Outlet Lake E. of Heart Lake | YELL0276 | Nymph Lake |
| YELL0101 | Yellowstone Lake South Arm OLI Sample Site #3 | YELL0289 | Lake of the Woods, Foot of Landmark Peak |
| YELL0103 | Lewis Lake North of South Entrance | YELL0290 | Beaver Lake near on Obsidian Creek |
| YELL0108 | Yellowstone Lake Southeast Arm OLI Sample Site | YELL0291 | Grizzly Lake North of Roaring |
| YELL0109 | Yellowstone Lake South Arm OLI Sample Site # 2 | YELL0296 | Lower Trilobite Lake between Dome & Holme |
| YELL0110 | Buffalo Lake Base of Madison P lateau | YELL0297 | Trilobite Lake between Dome & Holme |
| YELL0112 | Alder Lake on Promonotory | YELL0301 | Obsidian Lake |
| YELL0115 | Glade Lake at Base of Mount Shurz | YELL0305 | Gallatin Lake Headwaters of Gallatin River |
| YELL0116 | Yellowstone Lake South Arm OLI Station #1 | YELL0310 | Foster Lake Northwest of Sodabutte Creek |
| YELL0120 | Riddle Lake South of West Thumb | YELL0325 | Lost Lake West of Tower Ranger Station |
| YELL0121 | Shoshone Lake | YELL0341 | Fawn "Pass" Lake in Fawn Pass Saddle |
| YELL0129 | Pocket Lake West of Shoshone Lake | YELL0352 | Little Trumpeter Lake near from Tower Junction |
| YELL0134 | Scaup Lake Southeast of Old Faithful | YELL0353 | Big Trumpeter Lake near Tower Junction |
| YELL0135 | Yellowstone Lake West Thumb OLI Sample Site | YELL0357 | Mammoth Water Supply South of Mammoth |
| YELL0146 | Sylvan Lake near Sylvan Pass | YELL0365 | Ice Lake Reservoir Northwest at Base of Sepulcher |
| YELL0156 | Yellowstone Lake Southeast Stevenson Island OLI Site | YELL0366 | Blacktail Ponds  E of Mammoth |
| YELL0157 | Gooseneck Lake West of Norris Geyser | YELL0368 | Fawn Lake North Tip of Gardner's Hole |
| YELL0158 | Upper Gooseneck Lake near South of Gooseneck Lake | YELL0381 | McBride Lake |
| YELL0169 | Goose Lake near Norris Geyser Basin | YELL0382 | Mount Everts Lake #1 South Edge Mount Everts |

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YELL0172 | Goose Lake | YELL0383 | Cache Lake Northeast Solfatara Plateau |
| YELL0174 | Beach Springs Lake near Lake Junction | YELL0384 | Geode Lake Rim of Black Canyon of Yellowstone River |
| YELL0177 | Squaw Lake (Indian Pond) near Fishing Bridge | YELL0398 | Mammoth Beaver Pond (Little) East of Sepulcher |
| YELL0189 | Trout Lake Southwest from Northeast Entrance | YELL0402 | Crevice Lake on Yellowstone River |
| YELL0207 | West White Lake North of Pelican Valley | YELL0403 | Little Slide Lake Northof Mammoth |
| YELL0209 | Harlequin Lake West of Madison Junction | YELL0404 | Mammoth Beaver Pond (Big) E.of Sepulcher |
| YELL0219 | East White Lake NorthPelican Valley | YELL0412 | Middle Rainbow Lake on Sepulcher |
| YELL0223 | Cygnet Lake#3 North of Mary. | YELL0413 | Sportsman Lake West of Electric Peak |
| YELL0227 | E. Tern Lake Northof Pelican Valley | YELL0427 | Crag Lake Head of East Fork of Specimen Creek |
| YELL0228 | West Tern Lake Northof Pelican Valley | YELL0428 | High Lake East Fork of Specimen Creek |
| YELL0229 | Cygnet Lake#4 North of Mary | YELL0429 | Cresent Lake North Fork Specimen Creek |
| YELL0230 | Cygnet Lake#5 North of Mary | YELL0444 | (No Name) |

The DSS did not make an assessment for any of the 96 lake locations concerning the ‘Natural Organic Acid Impacted’ category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS identified 83 lakes as insensitive to acid (true in the ‘Insensitive to Acid’ category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (> 200 μeq/L) and high specific conductance values (≥ 40 μS/cm). The 12 lakes listed in Table 12-7 were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the ‘Insensitive to Acid’ category).

**Table 12-7: YELL lake locations rated false in the ‘Insensitive to Acid’ category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YELL0030 | Robinson Lake West of Bechler Ranger Station | YELL0235 | Dewdrop Lake North of Fishing Bridge |
| YELL0110 | Buffalo Lake Base of Madison Plateau | YELL0240 | Fern Lake |
| YELL0133 | Summit Lake Southwest from Bisquit Basin | YELL0242 | Wrangler Lake at Artist Point |
| YELL0134 | Scaup Lake Southeast of Old Faithful | YELL0267 | Mirror Lake on Southern Mirror Plateau |
| YELL0168 | Dryad Lake West of Yellowstone Lake | YELL0290 | Beaver Lake near Obsidian Creek |
| YELL0194 | Mary Lake Southwest of Mary | YELL0301 | Obsidian Lake |

All of the 96 lakes were found to not suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). In 93 of these cases, the nitrate concentration was less than 10 μeq/L.

The DSS evaluates all of the locations in terms of the completeness of the input data. The 93 locations containing six or all seven inputs have complete datasets. The other 3 lake locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Lakes – Extreme Water Chemistry Values*

Table 12-8 lists the results of the DSS for extreme values of water chemistry parameters in lakes in YELL. Figure 12-6 graphically represents these results.

**Table 12-8: DSS Results for Extreme Lake Values - YELL**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 0 | 87 | 17 | 0 | 13 | 91 | 7 |
| -0.59 to -0.20 | 0 | 2 | 1 | 0 | 0 | 3 | 86 |
| -0.19 to 0.20 | 96 | 0 | 0 | 96 | 1 | 0 | 0 |
| 0.21 to 0.60 | 0 | 7 | 13 | 0 | 2 | 0 | 0 |
| 0.61 to 1.00 | 0 | 0 | 65 | 0 | 80 | 2 | 3 |

The DSS did not make an assessment for any of the 96 lake locations concerning the 'Acid Deposition Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS identified 89 lake locations as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These lakes have high ANC (> 100 μeq/L), specific conductance values (> 40 μS/cm), and base cation concentrations (> 300 μeq/L). Seven lakes were found to be sensitive but not impacted (true in the 'Sensitive but Unimpacted' category): Grassy Lake Reservoir 100 m above Dam (YELL0004), Robinson Lake West of Bechler Ranger Station (YELL0030), Summit Lake Southwest of Bisquit Basin (YELL0133), Summit Lake Southwest of Bisquit Basin, Dryad Lake West of Yellowstone Lake (YELL0168), Mary Lake Central Plateau (YELL0194), Wrangler Lake at Artist Point (YELL0242), and Mirror Lake on Southern Mirror Plateau (YELL0267). This location had moderate buffering capabilities, but low nitrate and sulfur concentrations.

Only 18 of the lakes locations were classified as not showing acid effects from geologic sulfur (false in the 'Geologic Sulfur Impacted' category). This is mainly attributable to the substantial buffer capacity of these lakes. Sulfate concentrations in these locations are low (< 30 μeq/L). A majority of the locations, 78, were found to show acidic effects from geologic sulfur (true in the ‘Geologic Sulfur Impacted’ category). They are listed in Table 12-6 above. Many of these locations have moderate to high sulfate concentrations, but have neutral or slightly basic pH (≥ 7).

The DSS did not make an assessment for any of the 96 lake locations concerning the ‘Natural Organic Acid Impacted’ category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS identified 82 lakes as insensitive to acid (true in the ‘Insensitive to Acid’ category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (> 200 μeq/L) and high specific conductance values (≥ 40 μS/cm). Thirteen lakes were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the ‘Insensitive to Acid’ category). These include the 12 lakes listed in Table 12-7 and Lewis Lake North of South Entrance (YELL0103).

Of the 96 lake locations, 94 were found to not suffer from the results of disturbance or land use (false in the ‘Disturbance or Land Use Impacted’ category). Most of these locations had nitrate concentration less than 10 μeq/L. The others were extremely well buffered, such that their nitrate concentrations were small compared to their buffering capacity. Two lakes were found to be effected by acid generated by disturbances or land use practices (true in the ‘Disturbance or Land Use’ category): Yellowstone Lake Southeast Arm OLI Sample Site (YELL0108) and Yellowstone Lake Southeast Stevenson Island OLI Site (YELL0156). At these locations, the nitrate concentration exceeded 75 μeq/L.

**Figure 12-6: Charts of DSS Results for Extreme Lake Values - YELL**

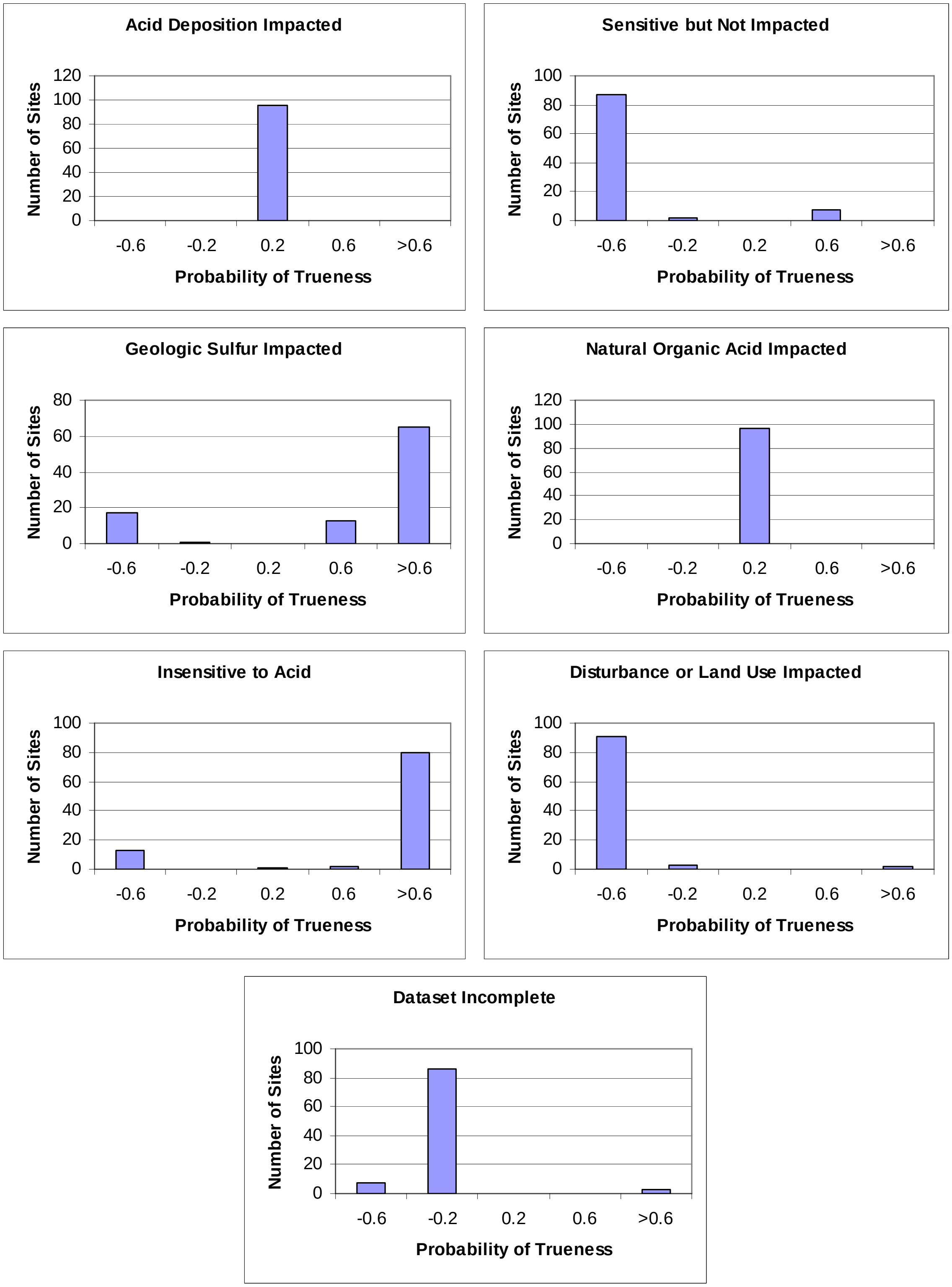
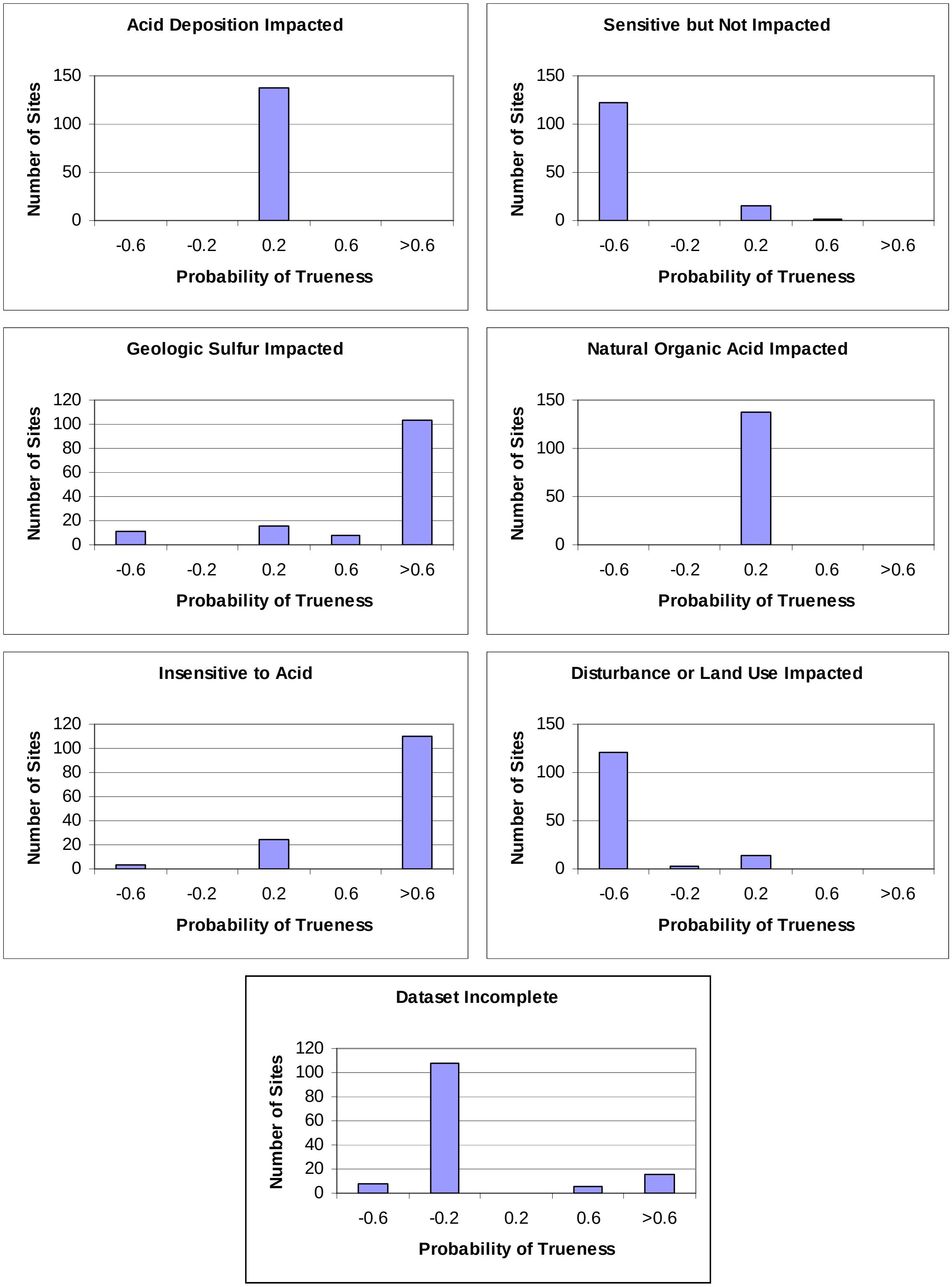


**Figure 12-7: Charts of DSS Results for Average Stream Values - YELL**



*Streams - Average Water Chemistry Values*

Table 12-9 lists the results of the Synthesis DSS for average water chemistry values at streams in YELL and Figure 12-7 represents this data graphically.

**Table 12-9: DSS Results for Average Stream Values - YELL**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 0 | 122 | 11 | 0 | 3 | 121 | 8 |
| -0.59 to -0.20 | 0 | 0 | 0 | 0 | 0 | 3 | 108 |
| -0.19 to 0.20 | 138 | 15 | 16 | 138 | 25 | 14 | 0 |
| 0.21 to 0.60 | 0 | 1 | 8 | 0 | 0 | 0 | 6 |
| 0.61 to 1.00 | 0 | 0 | 103 | 0 | 110 | 0 | 16 |

Seven of the stream sites had only one data parameter for the DSS. Four of these sites had only specific conductance; the DSS makes recommendations with no certainty for all of the categories for these streams. The other three sites had only nitrate concentrations. The DSS makes recommendations with no certainty for all of the categories for this stream except for Disturbance or Land Use Impacted.

The DSS did not make an assessment for any of the 138 stream locations concerning the 'Acid Deposition Impacted' category. This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS identified 122 stream locations as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). These lakes have high ANC (> 500 μeq/L), specific conductance values (> 50 μS/cm), and base cation concentrations (> 750 μeq/L). One stream, Grassy Creek at Grassy Lake Outlet (YELL0005), was found to be sensitive but not impacted (true in the 'Sensitive but Unimpacted' category). This location had moderate buffering capabilities, but low nitrate and sulfur concentrations.

Only 11 of the stream locations were classified as not showing acid effects from geologic sulfur (false in the 'Geologic Sulfur Impacted' category). This is mainly attributable to the substantial buffer capacity of these lakes. Sulfate concentrations in these locations are low (< 25 μeq/L). A majority of the locations, 111, were found to show acidic effects from geologic sulfur (true in the 'Geologic Sulfur Impacted' category) (Table 12-10). Many of these locations have moderate to high sulfate concentrations, but have neutral or slightly basic pH (≥ 7).

**Table 12-10: YELL stream locations rated true in the 'Geologic Sulfur Impacted' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YELL0017 | Lewis River at Mouth, near South Entrance | YELL0273 | Timothy Creek at Mouth |
| YELL0019 | Snake River above Lewis River. South Entrance, | YELL0274 | Cascade Creek. above Divide near Canyon Village |
| YELL0021 | Bechler River at Mouth near Bechler Ranger Station | YELL0280 | Miller Creek at Mouth |
| YELL0022 | Lewis River near Mouth near South Boundary | YELL0281 | Cougar Creek at Highway 287 |
| YELL0044 | Boundary Creek near Bechler Ranger Station | YELL0286 | Duck Creek at Highway 191 Bridge |
| YELL0064 | Unnamed Spring at Pit Plateau Trail Head | YELL0287 | Calfee Creek at Mouth |
| YELL0073 | Lewis River above Aster Creek | YELL0299 | Cache Creek at Mouth |
| YELL0079 | Beaver Creek at Mouth at Heart Lake, | YELL0306 | Supply Spring near Tower Fall |
| YELL0092 | Heart Lake | YELL0312 | Soda Butte Creek near Lamar Ranger Station |
| YELL0094 | Witch Creek at Mouth at Heart Lake, | YELL0313 | Soda Butte Spring at Soda Butte, |
| YELL0095 | Yellowstone River above Cabin Creek | YELL0314 | Obsidian Creek near Mammoth |
| YELL0097 | Lewis Lake, | YELL0320 | Indian Creek Divide near Mammoth |
| YELL0111 | Beaver Dam Creek near Mouth | YELL0321 | Gardner River above Divide Dam near Mammoth |
| YELL0122 | Shoshone Lake, | YELL0322 | Panther Creek above Divide Dam near Mammoth |
| YELL0131 | Southeast Arm Yellowstone Lake | YELL0329 | Lost Creek near Tower Junction |
| YELL0136 | Unnamed Tributary From Hot Spring near Well | YELL0330 | Unnamed Tributary To Gallatin River near Divide Lake |
| YELL0137 | Firehole River above Divide Dam near Old Faithful | YELL0331 | Lost Creek near Tower Junction Ranger Station |
| YELL0138 | Herron Creek near Outflow | YELL0338 | Unnamed Spring near Divide Lake |
| YELL0141 | Iron Spring Creek above Old Faithful Sewage Lag | YELL0342 | Pebble Creek near Tower Junction |
| YELL0142 | Iron Spring Creek below Old Faithful Sewage Lag | YELL0344 | Unnamed Spring near Crowfoot Ridge |
| YELL0143 | Iron Spring Creek near Old Faithful | YELL0346 | Gallatin River |
| YELL0148 | Arnica Creek near West Thumb, | YELL0347 | Lamar River near Tower Falls Ranger Station |
| YELL0154 | Middle Creek at East Entrance | YELL0348 | Glen Creek above Rustic Falls above Tributary |
| YELL0155 | Yellowstone Lake near Sand Point | YELL0349 | Glen Creek Tributary above Rustic Falls near Mammoth |
| YELL0159 | Cub Creek at East Entrance Road, | YELL0350 | Glen Creek above Rustic Falls near Mammoth |
| YELL0160 | Yellowstone Lake near Lake Butte | YELL0359 | Lava Creek above Lupine Creek near Mammoth |
| YELL0165 | Bridge Creek near Fishing Bridge | YELL0360 | Glen Creek at Mammoth Divide |
| YELL0166 | Spring at Whiskey Flats Picnic Area, | YELL0361 | Slough Creek near Tower Junction, |
| YELL0167 | Yellowstone Lake at Bridge Bay | YELL0362 | Blacktail Deer Creek near Mammoth |

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YELL0173 | Tangled Creek near Fountain Paint Pot | YELL0372 | Sand Spring near Mammoth |
| YELL0178 | Fairy Creek near Fountain Paint Pot | YELL0374 | Sand Spring Tributary near Mammoth, |
| YELL0179 | Yellowstone River at Fishing Bridge | YELL0377 | Unnamed Tributary to Fan Creek |
| YELL0181 | Sentinel Creek near Fountain Paint Pot | YELL0378 | Fan Creek above Unnamed Tributary |
| YELL0183 | Yellowstone River at Yellowstone Lake Outlet | YELL0379 | Unnamed Tributary from Blacktail P |
| YELL0184 | Yellowstone River at Fishing Bridge | YELL0380 | Blacktail Deer Creek below Tributary |
| YELL0185 | Pelican Creek. below Astringent Creek | YELL0386 | Gardner River above Mammoth Spring Outflow |
| YELL0186 | Pelican Creek below Astringent Creek | YELL0387 | Mammoth Hot Spring near Mammoth |
| YELL0187 | Yellowstone River below Fishing Bridge | YELL0388 | Mammoth Spring Outflow at Mammoth |
| YELL0190 | Nez Perce Creek near Fountain Paint Pot | YELL0389 | Clematis Creek at Mammoth |
| YELL0192 | Astringent Creek at Mouth | YELL0390 | Gardner River Sinkhole Divide at Mammoth |
| YELL0204 | Firehole River near West Yellowstone | YELL0400 | Hot River at Mammoth |
| YELL0205 | Old Hotel Spring near Paint Pot Fountain | YELL0401 | Gardner River near Mammoth |
| YELL0213 | Supply Spring at Madison Junction | YELL0409 | Soda Butte Creek Southeast of Silver Gate |
| YELL0214 | Firehole River at Madison Junction | YELL0410 | Specimen Creek above Specimen Creek Campground |
| YELL0215 | Gibbon River at Grand Lake Road Brigde | YELL0416 | Soda Butte Creek below Tailings Pipe |
| YELL0216 | Madison River below Madison Junction | YELL0417 | Butte Creek |
| YELL0217 | Madison River near Madison Junction | YELL0418 | Miller Creek at Cooke City Highway |
| YELL0218 | Gibbon River near West Yellowstone | YELL0419 | Yellowstone River above Bear Creek |
| YELL0224 | Madison River near West Yellowstone | YELL0431 | Stillwater River at Daisy Pass #4 |
| YELL0255 | Castle Creek below Divide Dam | YELL0432 | Stillwater River at Daisy Pass #3 |
| YELL0256 | Lamar River above Willow Creek | YELL0433 | Slough Creek by Guard Station |
| YELL0257 | Willow Creek at Mouth | YELL0436 | Stillwater River at Ford |
| YELL0258 | Yellowstone River near Canyon Hotel | YELL0439 | Creek Draining Horseshoe Basin |
| YELL0259 | Castle Creek near Norris Junction | YELL0441 | Wounded Man Creek above Slough Creek |
| YELL0260 | Madison River above Hebgen Lake | YELL0442 | Boulder River, 3rd Order |
| YELL0266 | Gibbon River near Norris Junction | | |

The DSS did not make an assessment for any of the 138 stream locations concerning the ‘Natural Organic Acid Impacted’ category.  This is not due to any one factor, but the combination of average stream chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS identified 110 streams as insensitive to acid (true in the 'Insensitive to Acid' category). These streams would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These streams have high ANC values, specific conductance, and base cation concentrations. Three streams listed in Table 12-7 were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category): Unnamed Tributary from Hot Spring (YELL0136), Astringent Creek at Mouth (YELL0192), and Stillwater River at Daisy Pass #3 (YELL0432).

All of the 124 streams where the DSS made a classification were found to not suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). In 121 of these cases, the nitrate concentration was less than 10 μeq/L.

The DSS evaluates all of the locations in terms of the completeness of the input data. The 113 locations containing six or all seven inputs, plus three additional locations, have complete datasets. The other 22 stream locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Streams - Extreme Water Chemistry Values*

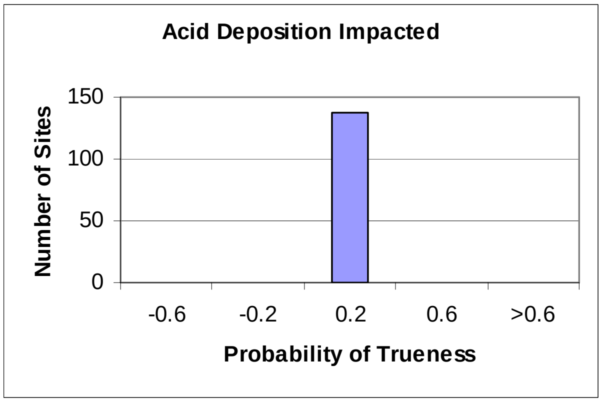
Table 12-11 contains the results of the Synthesis DSS of extreme water chemistry value for streams in North Cascades National Park. Figure 12-8 includes graphs of the data in this table.

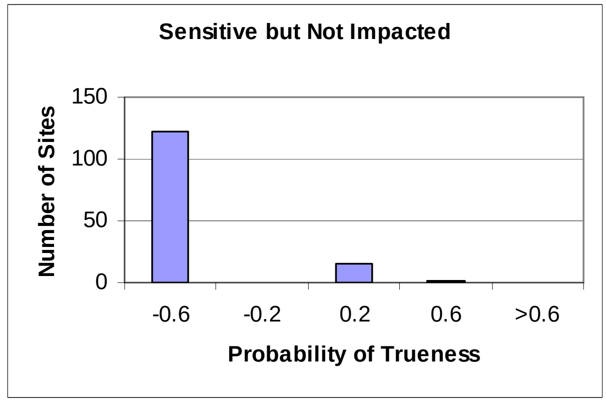
**Table 12-11: DSS Results for Extreme Stream Values - YELL**

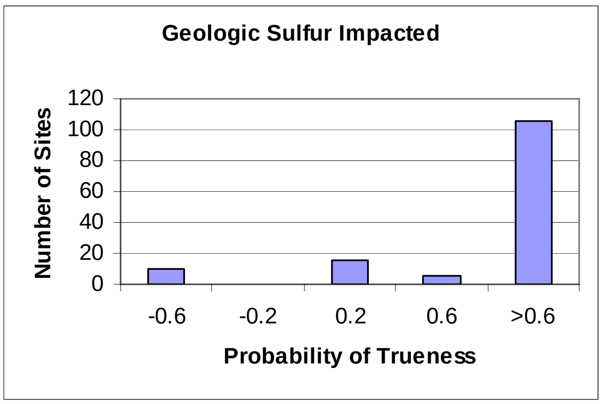
| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 0 | 122 | 10 | 0 | 3 | 119 | 8 |
| -0.59 to -0.20 | 0 | 0 | 0 | 0 | 0 | 4 | 108 |
| -0.19 to 0.20 | 138 | 15 | 16 | 138 | 25 | 14 | 0 |
| 0.21 to 0.60 | 0 | 1 | 6 | 0 | 0 | 1 | 6 |
| 0.61 to 1.00 | 0 | 0 | 106 | 0 | 110 | 0 | 16 |

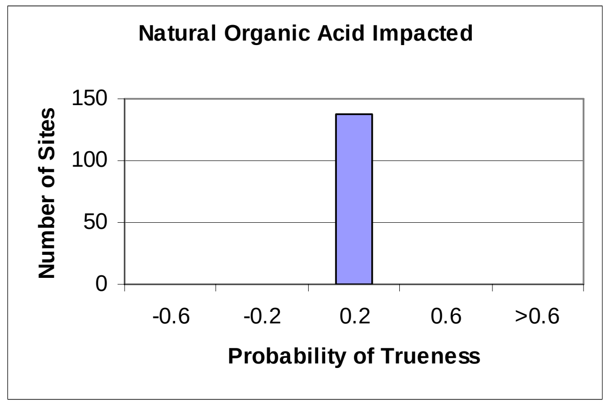
For the 'Acid Deposition Impacted', 'Sensitive but Unimpacted', 'Natural Organic Impacted', and 'Insensitive to Acid' categories, the DSS result distribution using extreme water chemistry values for streams at YELL was exactly the same as using average water chemisty values. This is because 71% of all stream locations were ananalyzed for ANC one time or less. Thus, the mean values are the same as the extreme values.

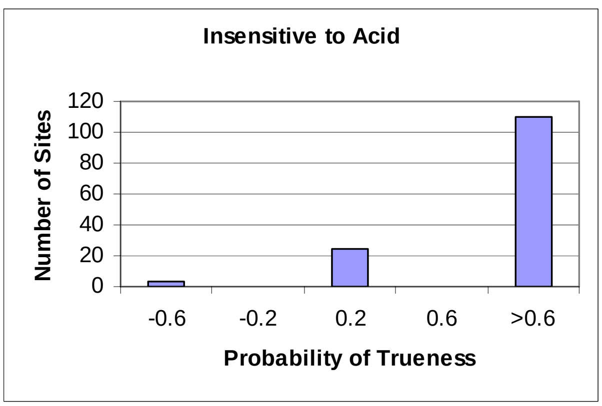
**Figure 12-8: Charts of DSS Results for Extreme Stream Values - YELL**

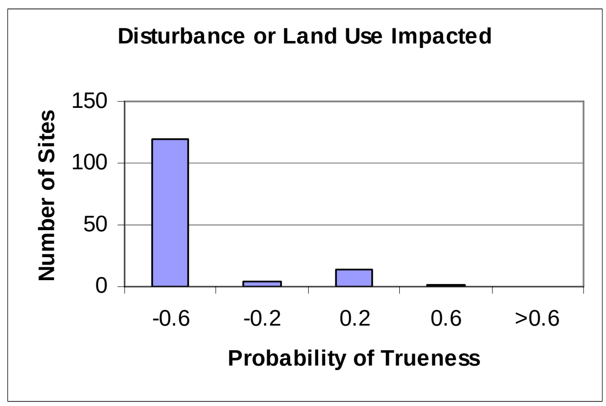


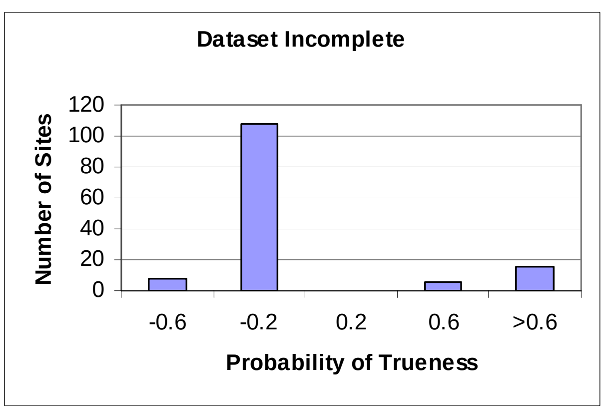



Only 10 of the stream locations were classified as not showing acid effects from geologic sulfur (false in the ‘Geologic Sulfur Impacted’ category). This is mainly attributable to the substantial buffer capacity of these streams. Sulfate concentrations in these locations are low (< 25 μeq/L). A majority of the locations, 112, were found to show acidic effects from geologic sulfur (true in the ‘Geologic Sulfur Impacted’ category). These locations include the 111 listed in Table 12-10 and Unnamed Tributary to Lewis River below Lewis Falls (YELL0069). Many of these locations have moderate to high sulfate concentrations, but have neutral or slightly basic pH (≥ 7).

Of the 124 streams where the DSS made a classification, 123 were found to not suffer from the results of disturbance or land use (false in the ‘Disturbance or Land Use Impacted’ category). In 120 of these cases, the nitrate concentration was less than 10 μeq/L. One location was found to be effected by acid generated from environmental disturbance or land use practices: Yellowstone River above Bear Creek (YELL0419). At this location, the nitrate concentration was 43 μeq/L.

### Analysis

## Conclusion

The data for Yellowstone NP used for this analysis tend to be from prior to 1980. Data from the lakes generally contain all parameters used by the DSS except for DOC, which is present for only 8% of samples. The DSS judged the greatest potential impact to be from geologic sulfur, with 80% of lakes judged to have potential impact. Sensitivity to acidic deposition was judged to be possible for 12 lakes, but none were judged to have been impacted by acidic deposition. No impacts from disturbance or land use were thought to be likely. Because only 8% of samples had data for DOC the possible effects of natural organic acids were ambiguous.

Data for streams tend to not have any parameters use by the DSS (60% of samples). For those 138 stream samples with data used by the DSS most included all parameters used by the DSS except for DOC. Results from the DSS were very similar to those for lakes, with geologic sulfur impacts judged to be most likely. Also, a few samples indicated some sensitivity to acidic deposition but none indicated impact in this category. Impacts from disturbance or land use and from natural organic acids did not seem to occur in any samples; however, only 13% of stream samples included data for DOC.

# Chapter 13 - Air and Water Quality in the Sierra Nevada Region

## Environmental Setting

The Sierra Nevada is the dominant landform in California. It is comprised of a large granitic batholith that extends 640 km in length and 80 km in width. The High Sierra was produced by three stages of folding, faulting, and uplift. The first began more than 200 million years ago and was followed by erosion and subsidence. The second stage of uplift occurred about 135 million years ago and was accompanied by batholithic intrusions of granite. This uplift was also followed by a period of erosion. Beginning with the Tertiary Period, a final stage occurred, consisting of four main uplifts and several lesser ones, which raised the range as a series of fault blocks many thousand feet higher than the depression of the eastern block now occupied by the Owens River Valley. Three distinct glacial intervals occurred during the Pleistocene Epoch glaciation, forming U-shaped valleys, cirques, and moraines, and leaving behind glacial eratics.

Heavy precipitation falls on the western slope of the Sierra Nevada, largely as snow at the higher elevations. The eastern slope lies in the rain shadow of the high mountains and is much drier. Wilderness sections of Yosemite (YOSE) and Sequoia and Kings Canyon (SEKI) National Parks, together with national forest wilderness areas in the Sierra Nevada, comprise the largest roadless area in the contiguous United States (Schoenherr 1992). Annual precipitation increases about 17 cm for every 300 m of elevation up to about 2,400 m elevation. Above that level, most of the moisture has been extracted from the air masses, and precipitation lessens (Barbour et al. 1993). Thus, the high peaks areas are quite dry.

Water is the primary limiting factor that determines the distribution and abundance of many plants and animals throughout California by shaping the landscape and providing a range of habitat conditions. Lakes, streams, and wetlands support a rich diversity of plants and animals in both the aquatic and surrounding riparian habitat. However, these aquatic and riparian systems are the most altered and impaired habitats in the Sierra Nevada (Kondolf et al. 1996) and likely in the state. Dams and water diversions to meet downstream demands of a growing human population have severely impacted water flows, temperature, and biodiversity. In addition, riparian and in-stream habitats have been severely altered by mining, grazing, and timber harvest. Excessive sediment yields due to up-watershed disturbance, introduction of non-native fish species, habitat degradation, and water quality degradation have all contributed, both regionally and locally, to impaired aquatic and riparian condition and function.

## Air Quality

Air quality in remote sections of the Sierra Nevadas is among the best in the United States. However, southern airsheds on the west side of the Sierra Nevada (including those in SEKI and YOSE) experience elevated ozone concentrations and nitrogen deposition, especially during summer.

$SO_2$ emissions in California have been low since the early 1980s; thus, $SO_2$ and particulate $SO_4^{2-}$ levels tend to be of lesser concern than other pollutants. Emissions of $NO_X$ from motor vehicles and stationary sources have played major roles in a number of significant air pollution problems in California.

Class I areas adjacent to the central and southern San Joaquin Valley are also potentially exposed to high levels of emissions. These areas include YOSE, SEKI, and USDA Forest Service-managed Emigrant, Mokelumne, Ansel Adams, Domeland, John Muir and Kaiser Wilderness areas.

Except for coastal locations, which are affected by sea-salt $SO_4^{2-}$, S deposition averages less than 1 kg/ha/yr (equivalently, 3 kg/ha/yr as $SO_4^{2-}$) in all parks where monitoring has taken place. Multi-year $NO_3^-$ and $NH_4^+$ wet deposition rates were each in the range of 0.5 to 1.8 kg/ha/yr as N, yielding total wet N deposition rates of 0.8 to 3.0 kg/ha/yr. For individual years, total wet N deposition rates were as high as 4.4 and 5.7 kg/ha/yr in Sequoia National Park.

Emission control efforts have steadily reduced the ambient concentrations of many air pollutants throughout substantial portions of California. The trends are most apparent in the principal metropolitan areas. Declining pollutant levels in the urbanized regions potentially lead to reduced levels of pollutants downwind. Emissions of $NO_X$ in California generally rose throughout the 1970s, and subsequently decreased after 1980 in most air basins due to air pollution control programs. The exception was the San Joaquin Valley, where emissions continued to increase (CARB 1985). Although per vehicle $NO_X$ emissions were reduced substantially, these improvements were largely negated by population and industrial growth.

## Lake and Stream Chemistry

Acid anion concentrations in most western lakes are extremely low in fall samples, but limited analyses of lake chemistry in spring generally show higher concentrations of $NO_3^-$ and $SO_4^{2-}$ (Williams and Melack 1991). The extremely dilute nature of many western lakes raises concerns regarding potential increases in acid anions, derived from acidic deposition, during spring snowmelt. The Sierra Nevada and portions of the Cascade Mountains (including LAVO, SEKI, and YOSE) are particularly sensitive to potential acidic deposition aquatic effects because of the predominance of granitic bedrock, thin acidic soils, large amounts of precipitation, coniferous vegetation, and extremely dilute waters (McColl 1981, Melack et al. 1985, Melack and Stoddard 1991, Sullivan 2000). It appears that chronic acidification has not occurred to any significant degree. It is possible, however, that episodic effects may have occurred under current deposition regimes.

Concentrations of $SO_4^{2-}$ in western lakes are generally low, but in some cases, for example in part of Kings Canyon National Park, geologic sources are contributing substantial amounts of $SO_4^{2-}$ to lakewaters. Nitrate concentrations were virtually undetectable in most western lakes sampled by EPA's Western Lakes Survey in the fall (Landers et al. 1987). However, in some cases, fall $NO_3^-$ concentrations were surprisingly high. For example, in the Sierra Nevada about 10% of the lakes had $NO_3^-$ concentrations above 5 µeq/L (Sullivan and Eilers 1994). Thus, some high elevation lakes in the Sierra Nevada may be experiencing N deposition sufficiently high to cause chronic $NO_3^-$ leaching, and likely associated chronic and episodic acidification, albeit small in magnitude.

Most lakes receive the majority of their hydrologic input from water that has previously passed through the terrestrial catchment. As long as N retention in the terrestrial system remains high, as is generally the case for forested ecosystems, N concentrations in lakes will remain low in the absence of contributions from land use (e.g., agriculture) or other pollution sources. However, if N retention in the catchment is low and the lake has not yet acidified, N deposition can in some cases increase primary production. Lakes that are most likely to be low in base cations (therefore potentially sensitive to acid deposition) and also N-limited are often systems overlaying volcanic bedrock (these rocks may be high in P).

Spring snowmelt can flush into lakes and streams; N that was deposited in the snowpack from atmospheric deposition or N mineralized within the soil during winter. In general, $NO_3^-$ concentrations in the snowpack of the California mountains are slightly higher in the Sierra Nevada than in the Cascade Mountains in the northern portion of the state (Laird et al. 1986). In some alpine and subalpine western lakes, the concentration of $NO_3^-$ remains somewhat elevated throughout the growing season.

A substantial component of the $NO_3^-$ in western lakewaters may have been derived from mineralization of organic N and not directly from atmospheric deposition (Williams et al. 1996). It is likely that microbial activity under the snowpack plays an important role in both the production of inorganic N before the snowmelt begins and also in the immobilization of N during the initial phases of snowmelt before vegetation becomes active (Brooks et al. 1996). The recognized importance of mineralization, the production of inorganic N from the breakdown of organic material, and subsequent conversion to $NO_3^-$ (nitrification) as a source of streamwater $NO_3^-$ does not imply, however, that atmospheric N deposition is not driving this flux. It is likely that mineralization and nitrification processes release N to surface waters that was derived largely from deposition and was cycled through the primary production of the previous growing season.

Topographic relief is also a contributing factor to acidic deposition sensitivity in the West because the mountainous terrain contributes to major snowmelt events that may cause episodic pH and ANC depressions. These snowmelt events can result in multiple exchanges of the water volume in sensitive lakes. The short residence time of many high-elevation lakes not only contributes to elevated sensitivity to episodic acidification during snowmelt events, but also reduces the relative importance of in-lake alkalinity generation processes.

Episodic acidification is an important issue for surface waters in the Sierra Nevada. A number of factors pre-dispose such systems to potential episodic effects (Peterson and Sullivan 1998), including:

1. The abundance of dilute to ultra-dilute lakes (i.e., those having extremely low concentrations of dissolved solutes), exhibiting very low concentrations of base cations, and therefore ANC, throughout the year;

2. Large snowpack accumulations at the high elevation sites, thus causing substantial episodic acidification via the natural process of base cation dilution; and

3. Short retention times for many of the high-elevation drainage lakes, thus enabling snowmelt to rapidly flush lake basins with highly dilute meltwater.

In most cases, episodic pH and ANC depressions during snowmelt are driven by natural processes (mainly base cation dilution) and nitrate enrichment (cf. Wigington et al. 1990, 1993; Stoddard 1995). Where pulses of increased $SO_4^{2-}$ are found during hydrological episodes, they are usually attributable to S storage and release in streamside wetlands or S retention in watershed soils. This is probably attributable to the observation, based on ratios of naturally occurring isotopes, that most stream flow during episodes is derived from pre-event water. Water stored in watershed soils is forced into streams and lakes by infiltration of meltwater via the "piston effect." This is not necessarily the case for high-elevation watersheds in the Sierra Nevada and Cascade Mountains, however. Such watersheds often have large snowpack accumulations and relatively little soil cover. Selective elution of ions in snowpack can therefore result in relatively large pulses of both $NO_3^-$ and $SO_4^{2-}$ in drainage water early in the snowmelt (Sullivan 2000).

# Chapter 14 - Sequoia and Kings Canyon National Parks

## Background

### Description

Sequoia National Park, America's second national park, was created on September 25, 1890. It encompasses over 1,500 $km^2$ and includes not only the world famous giant sequoias but also part of the largest uncut mixed conifer forest remaining in the Sierra Nevada. Kings Canyon National Park encompasses the most rugged portion of the Sierra Nevada. Established in 1890 as General Grant National Park, this area became part of the newly created Kings Canyon National Park in 1940. Together, Sequoia and Kings Canyon National Parks (SEKI) encompass about 350,000 ha of contiguous parkland, and are managed as one unit by the NPS. They form an international biosphere reserve and are bounded on three sides by national forest wilderness areas.

Climate is highly variable throughout the parks and is strongly influenced by elevation and orographic effects. Foothills have hot dry summers and cold wet winters with occasional freezing temperatures. Mid-elevations have warm summer days with cold nights, occasional summer rain, and deep winter snow with freezing night temperatures. Alpine areas have cool summer days, cold to freezing nights, occasional summer rains, and deep winter snow with temperatures generally well below freezing.

Sequoia and Kings Canyon National Parks contain some 3200 lakes and ponds and approximately 2600 miles of rivers and streams. Three major rivers originate in these parks --Kings, Kaweah and Kern. These rivers provide valuable irrigation water to the rich agricultural lands in Fresno, Kern and Tulare counties as well as providing water for recreation and industrial activities outside the parks.

### Deposition

Located downwind of one of the most productive agricultural areas in the world, the San Joaquin Valley, Sequoia and Kings Canyon NPs periodically experience some of the worst air quality in the United States (Peterson and Arbaugh 1992, Cahill et al. 1996). Most of the parks' air pollution originates in the valley and is transported into these parks by prevailing winds (Roberts et. al. 1991). Four factors contribute to the area's high pollution levels: climate, lifestyle, population, and topography. Hot, dry summers create perfect conditions for smog formation. A spread-out, car-dependent society with the highest population growth in the state produces increasing numbers of mobile and small stationary emission sources. Bowl-like topography promotes nightly temperature inversions that trap and concentrate pollutants. Low Cl- and high $NH_4^+$ concentrations in rain, compared with snow, suggest that localized convective systems (as opposed to oceanic frontal systems during winter) are the main sources of ions in rainfall. Afternoon upslope air flow, induced by heating of air along the mountain slopes, transports air masses from the SJV to the upper reaches of Sequoia National Park on a daily basis during summer (Williams and Melack 1997b).

There has been a slow, continuous increase in atmospheric nitrogen deposition in park watersheds (Lynch et al. 1995), a local manifestation of a global phenomenon (Vitousek 1994, Vitousek et al. 1997, Moffat 1998). However, in spite of increasing nitrogen deposition, there has been a decrease in dissolved nitrogen leaving watersheds (Melack et al. 1998). The consequences of increased nitrogen deposition and retention on terrestrial plant communities are unknown.

There are four air quality stations located within Sequoia and Kings Canyon National Parks located at Ash Mountain, Grant Grove, Lookout Point, and Lower Kaweah (1999). The Ash Mountain and Lower Kaweah Stations are also collecting Wet Deposition data that began in 1983. CARB also collects Wet Deposition data at several other higher elevation sites. Continuous daily temperature and precipitation data have been collected for Ash Mountain since 1948, Grant Grove since 1949, and Lodgepole Campground since 1969.

Wet S deposition averaged less than 1 kg/ha/yr as S (equivalently, 3 kg/ha/yr as $SO_4^{2-}$), with individual years ranging as high as 1.2 to 1.4 kg/ha/yr in some monitoring locations. Multi-year $NO_3^-$ and $NH_4^+$ wet deposition rates were each in the range of 0.5 to 1.6 kg/ha/yr as N, yielding total wet N deposition rates of 1.1 to 3.0 kg/ha/yr. Annual wet N deposition rates were as high as 4.4 and 5.7 kg/ha/yr during some years at some locations in Sequoia National Park.

Extensive monitoring of wet deposition to high elevations of the Sierra Nevada was initiated in 1990 at nine sites (Melack et al. 1998). Concentrations of N measured in winter snow in the Emerald Lake watershed were among the most dilute measurements of N recorded in wet precipitation (Williams et al. 1995). $NO_3^-$ and $NH_4^+$ concentrations in non-winter precipitation were eight to nine times greater than in the snowpack (mean values, 20.7 and 23.4 μeq/L, respectively). The $SO_4^{2-}$ concentration in non-winter precipitation was also high, with a mean of 15.1 μeq/L. In contrast, the mean $Cl^-$ level measured in non-winter precipitation (4.2 μeq/L) was only slightly higher than the mean $Cl^-$ concentration in winter snowfall.

Mean annual wet $NH_4^+$ deposition was 0.70 kg/ha $NH_4^+$-N and mean annual wet $NO_3^-$deposition was 0.63 kg/ha $NO_3^-$-N. For both ions, the maximum wet loading rates were measured at Emerald Lake during water year 1987 (3.6 kg N/ha).

**Figure 14-1: Sulfate wet deposition at Giant Forest NADP site in Sequoia NP, 1980-2003.**

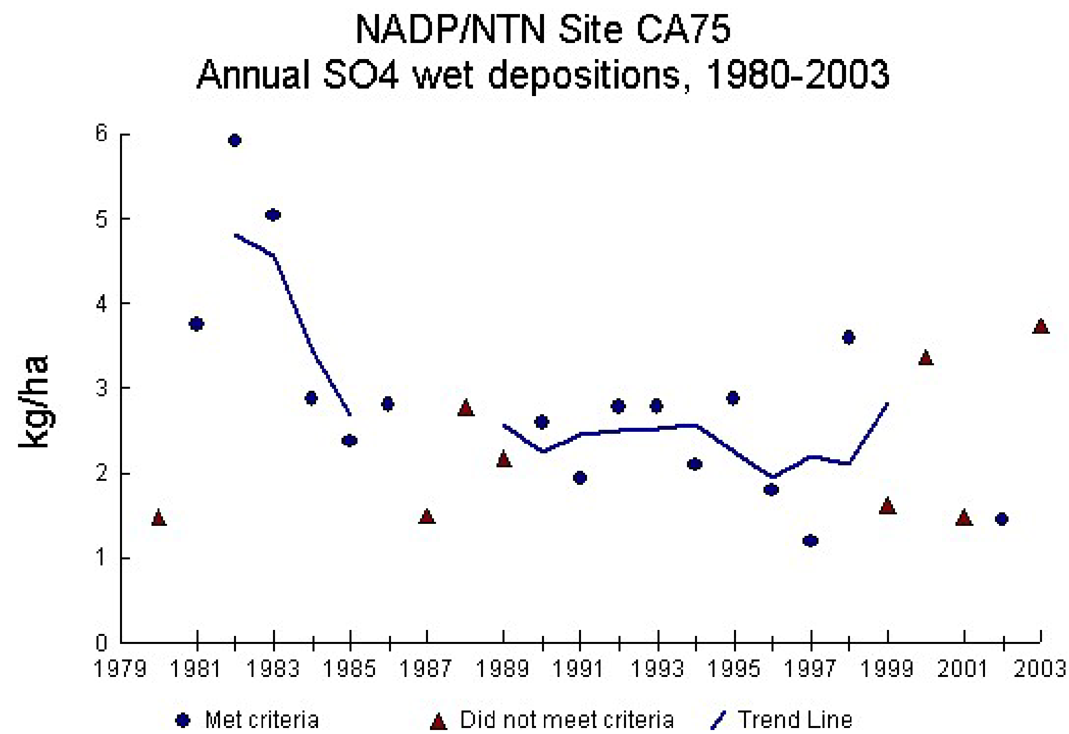
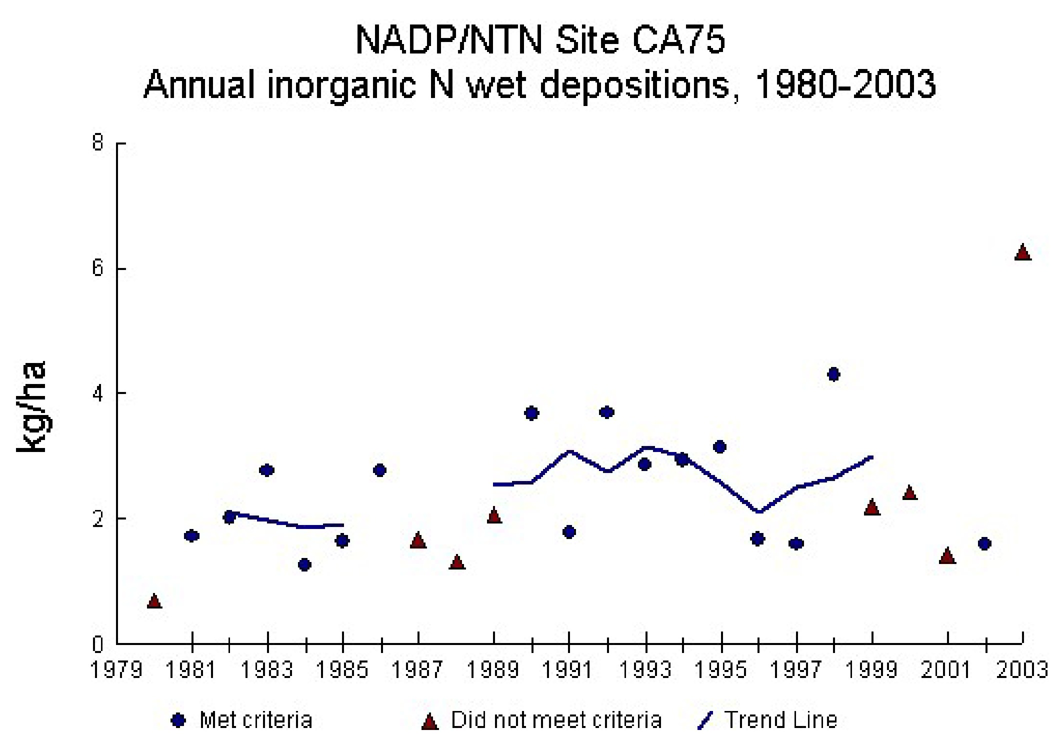



**Figure 14-2: Inorganic N wet deposition at Giant Forest NADP site in Sequoia NP, 1980-2003.**



The CASTNet dry deposition monitoring site located at Lookout Point within Sequoia National Park began operating February 4, 1997. The monitoring instrument measures ambient concentrations of gases and particles, and EPA uses a computer model to calculate the dry deposition rates from the measurements. The first calculations of dry-deposition rates for this site were released by EPA in November 2000, for 1999 only. The calculated annual dry deposition rates of N and S were 2.5 kg N/ha/yr and 0.7 kg S/ha/yr, respectively, for 1999. When combined with the wet deposition measurements from the nearby NADP/NTN site (located at Giant Forest, 15.5 km from the dry deposition monitor), the data indicate that the 1999 annual total deposition rates of N and S were 4.7 kg N/ha/yr and 1.3 kg S/ha/yr, respectively.

## Water Quality

In its natural condition, most of the surface water in these parks is rather pure. The concentrations of major cations, anions, and other dissolved constituents are so dilute that the electrical conductivities are very low. Alpine lakes and streams are generally below 20 μS/cm, and sometimes approach 2 μS/cm, the conductivity of distilled water. One consequence of such pure water is that it is poorly buffered (high lakes generally less than 50 μeq/L). Ionic content does increase with decreases in elevation. Conductivities may exceed 100 μS/cm by the time the rivers reach the park boundary. This is partially because marble, schist, and other metamorphic rocks that add significant dissolved constituents form a band along much of the western portion of these parks and at several other scattered locations. The waters are oligotrophic. Nutrients like phosphate or nitrate are generally less than 40 μg/L and ammonia is generally undetectable. The pH is normally slightly acidic, but varies from about 5.5 to 8.5, and some sites will exceed those extremes.

High elevation lakes and streams in the parks are very dilute and potentially sensitive to human-induced acid deposition. While chronic acidification presently is not a problem, episodic depression of acid-neutralizing capacity occurs during the snowmelt period (Melack and Sickman 1995, Melack et al. 1998), and episodic acidification occurs during the "dirty" rainstorms of summer and early fall (Stohlgren and Parsons 1987). If acid deposition increases in the future, episodic acidification will become more frequent, and can be expected to alter aquatic communities.

The concentrations of $SO_4^{2-}$ in the most acid-sensitive lakes tended to be relatively low; lakewater $SO_4^{2-}$ concentration ranged between about 3 and 10 µeq/L in most cases. Such concentrations are approximately what would be expected, assuming average $SO_4^{2-}$ concentrations in precipitation of about 3 to 5 µeq/L, negligible dry deposition, and less than 50% evapotranspiration. However, many of the WLS lakes in SEKI, including two of those having low ANC (< 50 µeq/L), had relatively high concentrations of $SO_4^{2-}$ (>> 10 µeq/L), which are likely the result of watershed sources of S. Nitrate concentrations were variable in the acid-sensitive lakes, ranging from near zero to 10 µeq/L.

Concentrations of $NO_3^-$ and $SO_4^{2-}$ in streams were correlated with the amount of snowmelt in each sub-basin. Inflows to Emerald Lake had elevated concentrations of $NO_3^-$ (~18 µeq/L) and $SO_4^{2-}$ (~9 µeq/L) at initiation of snowmelt, and then decreased as snowmelt progressed. The onset of snowmelt, and accompanying ionic pulses in streamwater, shifted from sub-basins with southwesterly aspect to those with northerly aspect (Williams and Melack 1989).

Fluxes and transformations of N were studied from 1985 to 1987 at Emerald Lake watershed and reported by Williams et al. (1995). The results of this study indicated that up to 90% of annual wet N deposition was stored in the seasonal snowpack. $NO_3^-$ and $NH_4^+$ were released from storage as an ionic pulse, with the first fractions of meltwater having concentrations of $NO_3^-$ and $NH_4^+$ as high as 28 µeq/L, compared with bulk snow concentrations < 5 µeq/L. The soil reservoir of organic N (81 keq/ha) was much greater than N storage in litter and biomass (12 keq/ha). Assimilation of N by vegetation was balanced by the release of N from soil mineralization, nitrification, and litter decay. Mineralization and nitrification processes in the watershed produced 1.1 keq/ha/yr of inorganic N, which represented 3.5 times the atmospheric N loading. During early snowmelt runoff, streamwater $NO_3^-$ concentrations reached their maximum levels (20 µeq/L). During the growing season, streamwater $NO_3^-$ concentrations were near zero (Williams et al. 1995).

Topaz Lake is located in a region of Sequoia National Park known as the table lands, about 6 km NNW of Emerald Lake. The geology of the watershed is dominated by fine grained granodiorite containing abundant mafic inclusions. Because of the low relief around the lake, it tends to expand during snowmelt and floods the meadow, forming a shallow bay. As the summer progresses, the lake level declines and the water retreats from the bay (Melack et al. 1993). Topaz Lake showed slightly elevated $NO_3^-$ concentrations, in the range of 2 to 8 µeq/L, during late summer and autumn of both 1991 and 1993.

Concentrations of $NO_3^-$ in the Emerald Lake outlet increased from 2-3 µeq/L in the fall to 10-13 µeq/L during spring runoff. The observed increases in $NO_3^-$, and also $SO_4^{2-}$, were attributed to preferential elution from the snowpack and low retention rates in the watershed. Inlake reduction of $NO_3^-$ and $SO_4^{2-}$ within Emerald Lake was relatively small, and most of the acid anions passed through the lake outlet (Melack et al. 1998).

## Aquatic Chemistry Data and DSS Results

### Horizon Report

The Horizon report was released for Sequoia and Kings Canyon NPs in July 1997. The report contains information on 456 water bodies in the parks. More water bodies exist, but were not sampled. Sequoia and Kings Canyon National Parks contain some 3200 lakes, 6% of which are included in the report and ponds and approximately 2600 miles of rivers and streams. The vast majority (97%) of water bodies in the report contained data relevant to the DSS. The report details 180 lakes, 259 streams, and 17 other water bodies in SEKI. Table 14-1 lists the number of sites that have data for each DSS component. The numbers indicate that data for streams, with the exception of DOC, is relatively more complete than data for lakes.

**Table 14-1: Chemistry Component Summary - SEKI**

| | Total | Lakes | Streams | Others |
|---|---|---|---|---|
| Number | 456 | 180 | 259 | 17 |
| Conductance | 429 | 170 | 244 | 15 |
| pH | 407 | 172 | 222 | 13 |
| ANC | 289 | 87 | 191 | 11 |
| DOC | 32 | 27 | 5 | 0 |
| Nitrate | 355 | 103 | 237 | 15 |
| Base Cations | 242 | 86 | 145 | 11 |
| Sulfate | 237 | 86 | 140 | 11 |

As is shown in Table 14-2, only 1% of lake sites and 4 % of stream sites had no data elements used by the DSS. For those sites with data, the data is somewhat complete. Forty-seven percent of lake sites and 53% of stream sites contained six or more of the data elements. As is typical at the parks studied, DOC data is fairly limited. At SEKI, data on alkalinity, base cations, and sulfate are available at just over half of the sites. This highlights the need for a standard set of chemical analyses were performed on water samples taken in the park.

**Table 14-2: Number of Elements Summary - SEKI**

| # of Elements | Total | Lakes | Streams | Others |
|---|---|---|---|---|
| 0 | 12 | 2 | 10 | 0 |
| 1 | 17 | 8 | 6 | 3 |
| 2 | 93 | 73 | 18 | 2 |
| 3 | 47 | 7 | 39 | 1 |
| 4 | 52 | 4 | 48 | 0 |
| 5 | 2 | 2 | 0 | 0 |
| 6 | 202 | 58 | 133 | 11 |
| 7 | 31 | 26 | 5 | 0 |

Of the 447 sites that had any data collection, including parameters not used by the DSS, 1 site was last sampled in the 1960s, 124 in the 1970s, 159 in the 1980s, and 163 in the 1990s. The data is relatively new in these parks, with 36% of sites sampled in the 1990s. Lake data is much newer than stream data, with 71% of lakes sampled during the 1990s, while only 9% of streams were last sampled during this decade. Almost two-thirds of the data in this report are 15 years old or older and may not indicate current water chemistry conditions. Additional sampling should take place so that the DSS can have up to date data for making recommendations.

Of the 289 locations that had alkalinity data, sampling occurred only once at 62% of them. At these locations, the mean and extreme ANC values are the same. Alkalinity results were based on more than 10 samples at only 10% of all locations. More frequent future sampling will aid in providining a more robust data set.

## ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

### *Mean ANC*

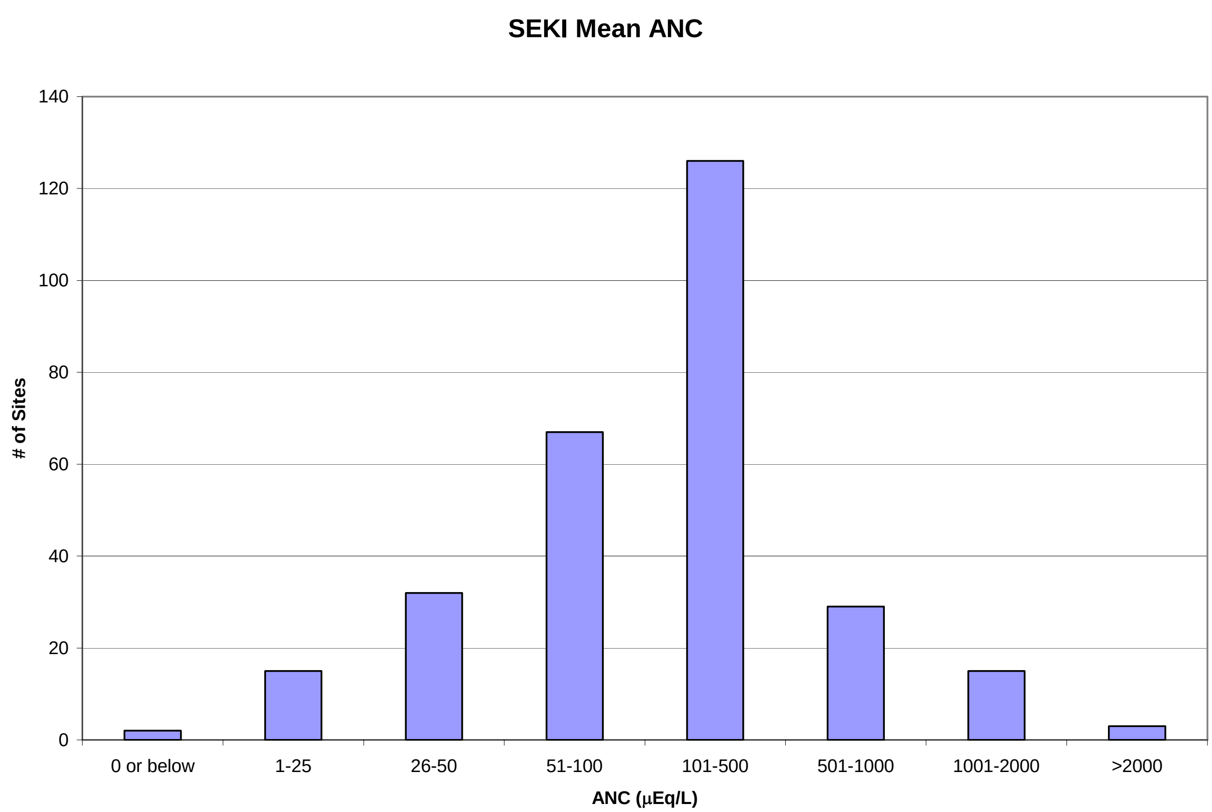
Of the 278 lake and stream sampling locations which contained data for ANC calculations, 17% had a mean ANC below 50 μeq/L and 6% had means below 25 μeq/L, including 2 sites that had means less than or equal to 0 μeq/L. The locations with means below 25 μeq/L are listed in Table 14-3.

**Table 14-3: Locations with mean ANC less than 25 μeq/L - SEKI**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| SEKI0379 | Lake C24 Outlet on Tributary to South Fork Kings River | -9.3 |
| SEKI0343 | Lake L7 Outlet on White Fork | -6.5 |
| SEKI0369 | Lake F2 Outlet on Tributary to South Fork Kings River | 0.5 |
| SEKI0364 | Lake F14 Outlet on Tributary to South Fork Kings River | 0.7 |
| SEKI0368 | Lake F13 Inlet on Tributary to South Fork Kings River | 2.3 |
| SEKI0387 | Lake C22 Outlet on Tributary to South Fork Kings River | 4.2 |
| SEKI0347 | Lake L11 Outlet on Tributary to White Fork | 6.0 |
| SEKI0108 | Big Arroyo near Little Five Lakes, CA | 10.0 |
| SEKI0445 | (No Name) | 14.5 |
| SEKI0427 | Lake B5 Outlet on Tributary to South Fork Kings River | 15.0 |
| SEKI0371 | Lake F11 Outlet on Tributary to South Fork Kings River | 15.8 |
| SEKI0373 | Lake F1 Outlet on Tributary to South Fork Kings River | 17.0 |
| SEKI0244 | (No Name) | 17.5 |
| SEKI0013 | Lake P35-1 Inlet #1 | 19.0 |
| SEKI0015 | Lake P35-1 Inlet #2 | 20.0 |
| SEKI0441 | Dusy Branch near Le Conte Ranger Station, CA | 20.0 |
| SEKI0447 | Darwin Canyon Creek | 20.0 |

Figure 14-3 contains a graph of the frequency distribution of mean ANC values in Sequoia and Kings Canyon National Parks.

**Figure 14-3: Frequency Distribution of Mean ANC Values - SEKI**




*Minimum ANC*

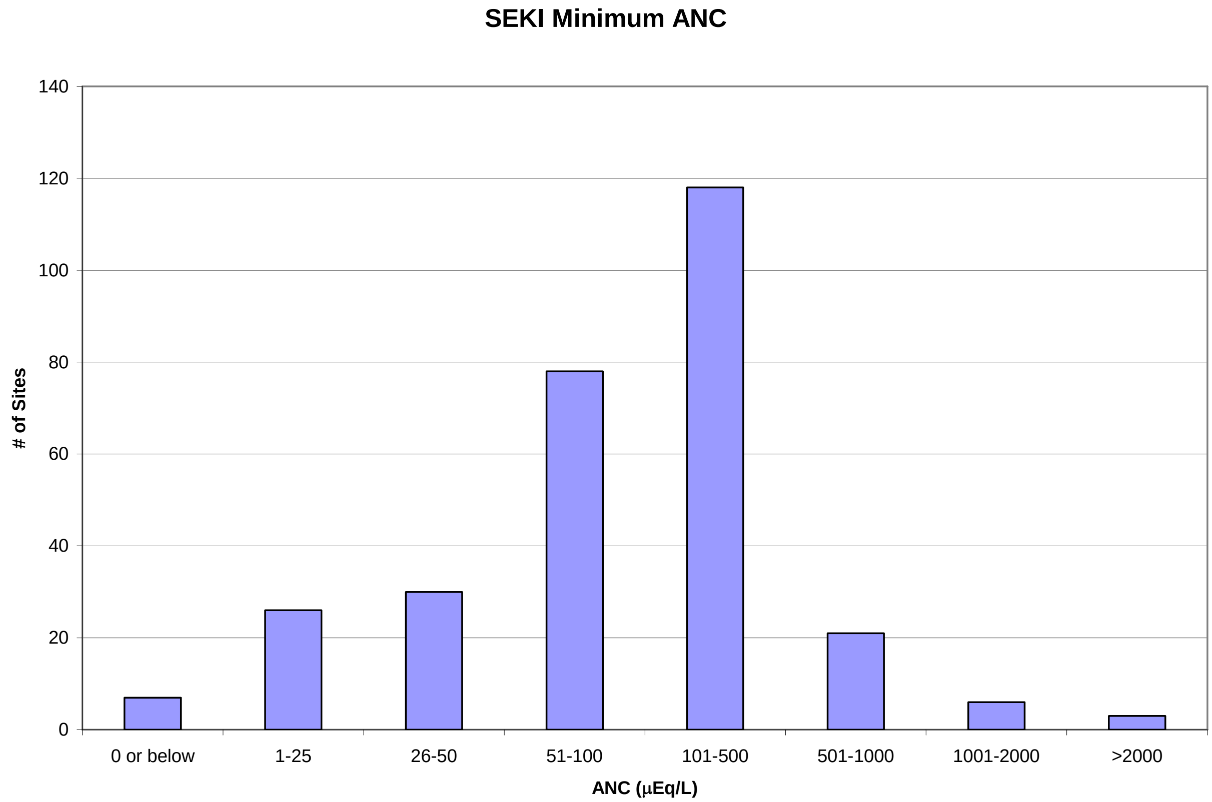
Of the 289 sampling locations which contained data for ANC calculations, 22% had minimum ANCs below 50 μeq/L, including 7 locations that had a minimum value less than or equal to 0 μeq/L. These locations are:

**Table 14-4: Locations with minimum ANC less than 0 μeq/L - SEKI**

| Site Code | Location Name | ANC (μeq/L) |
|---|---|---|
| SEKI0379 | Lake C24 Outlet on Tributary to South Fork Kings River | -14.0 |
| SEKI0343 | Lake L7 Outlet on White Fork | -7.0 |
| SEKI0369 | Lake F2 Outlet on Tributary to South Fork Kings River | -5.0 |
| SEKI0373 | Lake F1 Outlet on Tributary to South Fork Kings River | -3.0 |
| SEKI0364 | Lake F14 Outlet on Tributary to South Fork Kings River | -1.0 |
| SEKI0368 | Lake F13 Inlet on Tributary to South Fork Kings River | -0.5 |
| SEKI0387 | Lake C22 Outlet on Tributary to South Fork Kings River | -0.4 |

Figure 14-4 contains a graph of the frequency distribution of minimum ANC values inSEKI.

**Figure 14-4: Frequency Distribution of Minimum ANC Values - SEKI**




## Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

### *Lakes - Average Water Chemistry Values*

Table 14-5 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in Sequoia/Kings Canyon NP and Figure 14-5 includes graphical representations of this data.

Eight of the lake sites had only one data parameter for the DSS. Six sites had only nitrate concentrations. The DSS makes recommendations with no certainty for all of the categories for these lakes except for 'Acid Deposition Impacted' and 'Disturbance or Land Use Impacted'. Two sites had only pH values. The DSS makes recommendations with no certainty for all of the categories except 'Natural Organic Acid Impacted'.

**Table 14-5: DSS Results for Average Lake Values - SEKI**

| | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 88 | 77 | 0 | 113 | 37 | 65 | 27 |
| -0.59 to -0.20 | 4 | 4 | 0 | 3 | 3 | 23 | 59 |
| -0.19 to 0.20 | 63 | 78 | 178 | 6 | 92 | 83 | 4 |
| 0.21 to 0.60 | 21 | 13 | 0 | 55 | 1 | 1 | 7 |
| 0.61 to 1.00 | 2 | 6 | 0 | 1 | 45 | 6 | 81 |

Of the 115 lakes for which the DSS made an assessment about acid deposition, 92 or 52% of all lakes tested, are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category). Many of these lakes have high ANC values (> 50 μeq/L) and low nitrate concentrations (< 10 μeq/L). Twenty-three, or 13%, of the lake locations were identified as being acid deposition impacted (true in the 'Acid Deposition Impacted' category; they are listed in Table 14-6. These sites are characterized by low ANC values (≤ 51 μeq/L) and specific conductance values (≤ 12 μS/cm).

**Table 14-6: Lake locations that are true in the 'Acid Deposition Impacted' category.**

| Location ID | Location Name |
|---|---|
| SEKI0014 | Lake P35-1 Outlet |
| SEKI0016 | Forrester Lake Outlet |
| SEKI0027 | Eagle Lake |
| SEKI0028 | Franklin Lake |
| SEKI0029 | Mosquito Lake 4 |
| SEKI0031 | Mosquito Lake 3 |
| SEKI0032 | Mosquito Lake 2 |
| SEK0039I | Mosquito Lake 1 |
| SEKI0088 | Pond South of Spring Lake |
| SEKI0167 | Hitchcock Lake Outlet |
| SEKI0206 | Arctic Lake Outlet |
| SEKI0215 | Arctic Lake #2 |

| Location ID | Location Name |
|---|---|
| SEKI0216 | Arctic Lake #6 |
| SEKI0217 | Arctic Lake #3 |
| SEKI0219 | Arctic Lake #5 |
| SEKI0233 | Pear Lake |
| SEKI0244 | (No Name) |
| SEKI0312 | Swamp Lakes (Western) |
| SEKI0414 | Lake E4 Outlet |
| SEKI0427 | Lake B5 Outlet |
| SEKI0445 | (No Name) |
| SEKI0448 | (No Name) |
| SEKI0456 | Wahoo Lakes (Northwest) |

Eighty-one, or 46% of lakes are classified as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). Most of these lakes have high ANC (> 50 μeq/L) and high specific conductance values (≥ 15 μS/cm). The DSS did not make a recommendation on 44% of lake sites for this category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. Nineteen lake locations or 11% were found to be sensitive but not impacted (true in the 'Sensitive but Unimpacted' category). Most of the locations in this category have low ANC values (< 50 μeq/L), and all have low specific conductance values (≤ 10 μS/cm), and low base cation concentrations (< 100 μeq/L). This indicates that these locations do not have the buffering capacity to deal with future acid additions. These sites also have low nitrate concentrations (≤ 10 μeq/L) and low sulfate concentrations (< 30 μeq/L), which indicates that they have not yet been impacted by the presence of acidic compounds. The locations are listed in Table 14-7.

**Table 14-7: Lake locations that are rated true for the 'Sensitive but not Impacted' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| SEKI0014 | Lake P35-1 Outlet | SEKI0312 | Swamp Lakes (Western) |
| SEKI0016 | Forrester Lake Outlet | SEKI0403 | Lake C5 Outlet |
| SEKI0088 | Pond South of Spring Lake | SEKI0414 | Lake E4 Outlet |
| SEKI0133 | (No Name) | SEKI0427 | Lake B5 Outlet |
| SEKI0188 | Guitar Lake Outlet | SEKI0440 | (No Name) |
| SEKI0206 | Arctic Lake Outlet | SEKI0445 | (No Name) |
| SEKI0225 | Emerald Lake | SEKI0448 | (No Name) |
| SEKI0233 | Pear Lake | SEKI0451 | Heather Lake |
| SEKI0244 | (No Name) | SEKI0456 | Wahoo Lakes (Northwest) |
| SEKI0277 | (No Name) | | |

Eleven locations are listed as true in both the 'Acid Deposition Impacted' and 'Sensitive but not Impacted' categories. It seems counterintuitive that a single water body can be both 'Acid Deposition Impacted' and 'Sensitive but not Impacted'. There is a reasonable interpretation of these seemingly conflicting categories. These results demonstrate that the model allows for some uncertainty in definitely lumping a lake into one category at the exclusion of all others. The potential for it to be sensitive but unimpacted is due to the fact that there still is fairly high ANC and pH; impact, if it exists, would be gauged to be moderate. The potential for it to be acid deposition impacted is due to nitrate and sulfate values that could well be caused by acid deposition and to ANC that is low enough to have suffered some moderate impact.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

One hundred sixteen lakes, or 65%, were found to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted' category). This is due to high buffer capacity as represented by high ANC values (> 50 μeq/L) and low DOC concentrations (≤ 2.2 mg/L). The DSS found that 56 lakes, or 31%, were impacted by natural organic acids (true in the 'Natural Organic Acid Impacted' Category). This is due to a combination of low buffering capacity, represented by low ANC and specific conductance values, slightly acidic pH, and low nitrate and sulfate concentrations. These values indicate that the lakes have been impacted by acid, but nitrogen and sulfur deposition are not the cause. These locations are listed in Table 14-8.

## Figure 14-5: Charts of DSS Results for Average Lake Values - SEKI

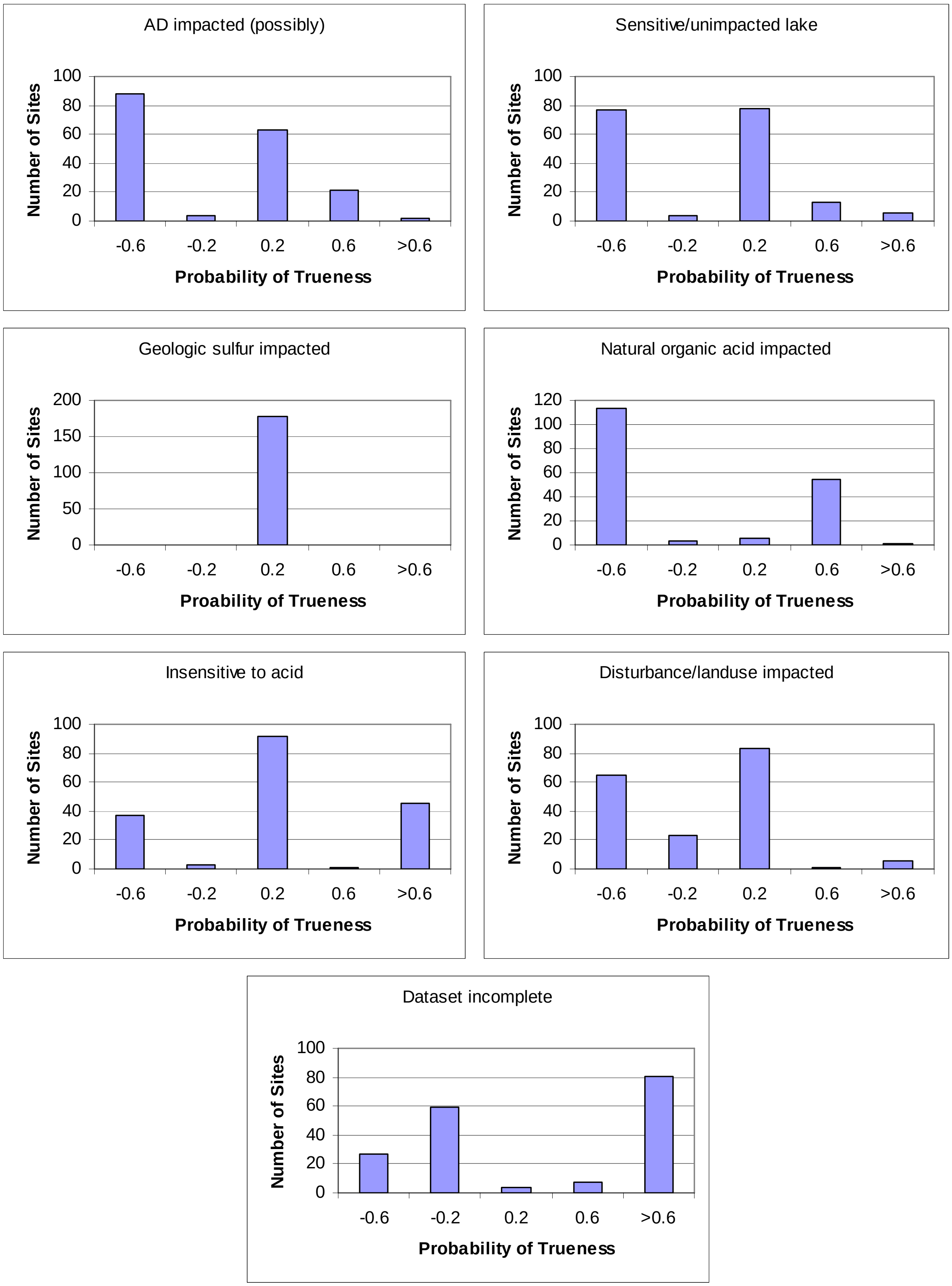


**Table 14-8: Lakes rated true in the 'Natural Organic Acid Impacted' category.**

| Location ID | Location Name |
|---|---|
| SEKI0010 | Hockett Lakes (Center) |
| SEKI0014 | Lake P35-1 Outlet |
| SEKI0016 | Forrester Lake Outlet |
| SEKI0019 | Franklin Lake Upper |
| SEKI0080 | Upper Monarch Lake |
| SEKI0087 | Meadow South of Spring Lake |
| SEKI0088 | Pond South of Spring Lake |
| SEKI0090 | Spring Lake |
| SEKI0109 | Small Pond on South Fork of Granite Creek |
| SEKI0138 | Pond on North Fork of Granite Creek |
| SEKI0143 | Eagle Scout Lake |
| SEKI0149 | Precipice Lake |
| SEKI0169 | Hamilton Lake |
| SEKI0188 | Guitar Lake Outlet |
| SEKI0206 | Arctic Lake Outlet |
| SEKI0211 | Tamarack Lake |
| SEKI0220 | Lion Lake |
| SEKI0225 | Emerald Lake |
| SEKI0232 | Moose Lake |
| SEKI0233 | Pear Lake |
| SEKI0235 | Pond East of Moose Lake |
| SEKI0239 | Lonely Lake |
| SEKI0241 | Pond North of Moose Lake |
| SEKI0253 | Rocky Pond Northeast of Moose Lake |
| SEKI0256 | L25-11 |
| SEKI0261 | Twin Lake |
| SEKI0326 | Lake L1 Outlet |
| SEKI0334 | Lake N6 |

| Location ID | Location Name |
|---|---|
| SEKI0338 | Lake L8 Outlet |
| SEKI0339 | Lake N3 Outlet |
| SEKI0343 | Lake L7 Outlet |
| SEKI0347 | Lake L11 Outlet |
| SEKI0348 | Lake L10 Outlet |
| SEKI0349 | Lake L9 Outlet |
| SEKI0364 | Lake F14 Outlet |
| SEKI0365 | Lake O21 Outlet |
| SEKI0366 | Lake F13 Outlet |
| SEKI0368 | Lake F13 Inlet |
| SEKI0369 | Lake F2 Outlet |
| SEKI0371 | Lake F11 Outlet |
| SEKI0372 | Lake O12 Outlet |
| SEKI0373 | Lake F1 Outlet |
| SEKI0374 | Lake F4 Outlet |
| SEKI0379 | Lake C24 Outlet |
| SEKI0386 | Lake D5 Outlet |
| SEKI0387 | Lake C22 Outlet |
| SEKI0389 | Lake C20 Outlet |
| SEKI0390 | Lake C21 Outlet |
| SEKI0392 | Lake C17 Outlet |
| SEKI0393 | Lake D4 Outlet |
| SEKI0401 | Lake D2 Outlet |
| SEKI0403 | Lake C5 Outlet |
| SEKI0405 | Lake E1 Outlet |
| SEKI0406 | Lake E5 Outlet |
| SEKI0414 | Lake E4 Outlet |
| SEKI0427 | Lake B5 Outlet |

The DSS did not make an assessment on 92 lakes, or 52%, in the 'Insensitive to Acid' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. Forty-six lakes, or 25%, are insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (> 67 μeq/L). The 40 remaining lakes were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category). The ANC values at these locations are below 60 μeq/L. These lakes are listed in Table 14-9.

**Table 14-9: Lakes that rate false in the 'Insensitive to Acid' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| SEKI0014 | Lake P35-1 Outlet | SEKI0364 | Lake F14 Outlet |
| SEKI0016 | Forrester Lake Outlet | SEKI0366 | Lake F13 Outlet |
| SEKI0019 | Franklin Lake Upper | SEKI0368 | Lake F13 Inlet |
| SEKI0087 | Meadow South of Spring Lake | SEKI0369 | Lake F2 Outlet |
| SEKI0088 | Pond South of Spring Lake | SEKI0371 | Lake F11 Outlet |
| SEKI0109 | Small Pond on South Fork of Granite Creek | SEKI0373 | Lake F1 Outlet |
| SEKI0133 | (No Name) | SEKI0379 | Lake C24 Outlet |
| SEKI0188 | Guitar Lake Outlet | SEKI0386 | Lake D5 Outlet |
| SEKI0200 | (No Name) | SEKI0387 | Lake C22 Outlet |
| SEKI0206 | Arctic Lake Outlet | SEKI0393 | Lake D4 Outlet |
| SEKI0225 | Emerald Lake | SEKI0403 | Lake C5 Outlet |
| SEKI0233 | Pear Lake | SEKI0414 | Lake E4 Outlet |
| SEKI | (No Name) | SEKI0427 | Lake B5 Outlet |
| SEKI0256 | L25-11 | SEKI0437 | (No Name) |
| SEKI | (No Name) | SEKI0438 | (No Name) |
| SEKI0312 | Swamp Lakes (Western) | SEKI0440 | (No Name) |
| SEKI0326 | Lake L1 Outlet | SEKI0445 | (No Name) |
| SEKI0338 | Lake L8 Outlet | SEKI0448 | (No Name) |
| SEKI0343 | Lake L7 Outlet | SEKI0451 | Heather Lake |
| SEKI0347 | Lake L11 Outlet | SEKI0456 | Wahoo Lakes (Northwest) |

Eighty-eight lakes, or 49%, were found to not suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). In all of these cases, the nitrate concentration was ≤ 9 μeq/L. For another 83, or 47%, the DSS did not make a classification for this category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. Only 7 lakes, or 4%, were considered by the DSS to be impacted by the effects of disturbance or land use (true in the 'Disturbance or Land Use Impacted' category. These locations are Arctic Lake #4 (SEKI0218), Lake L11 Outlet (SEKI0347), Lake F14 Outlet (SEKI0364), Lake F13 Inlet (SEKI0368), Lake C24 Outlet (SEKI0379) Lake C23 Outlet (SEKI0385), and Lake D5 Outlet (SEKI0386). Each of these locations has a nitrate concentration greater than 12 μeq/L.

The DSS evaluates all of the locations in terms of the completeness of the input data. The 84 locations containing six or all seven inputs, plus two additional locations, have complete datasets. The remaining 92 locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Lakes – Extreme Water Chemistry Values*

Table 14-10 lists the results of the DSS for extreme values of water chemistry parameters in lakes in Sequoia/Kings Canyon NP. Figure 14-6 graphically represents these results.

**Table 14-10: DSS Results for Extreme Lake Values - SEKI**

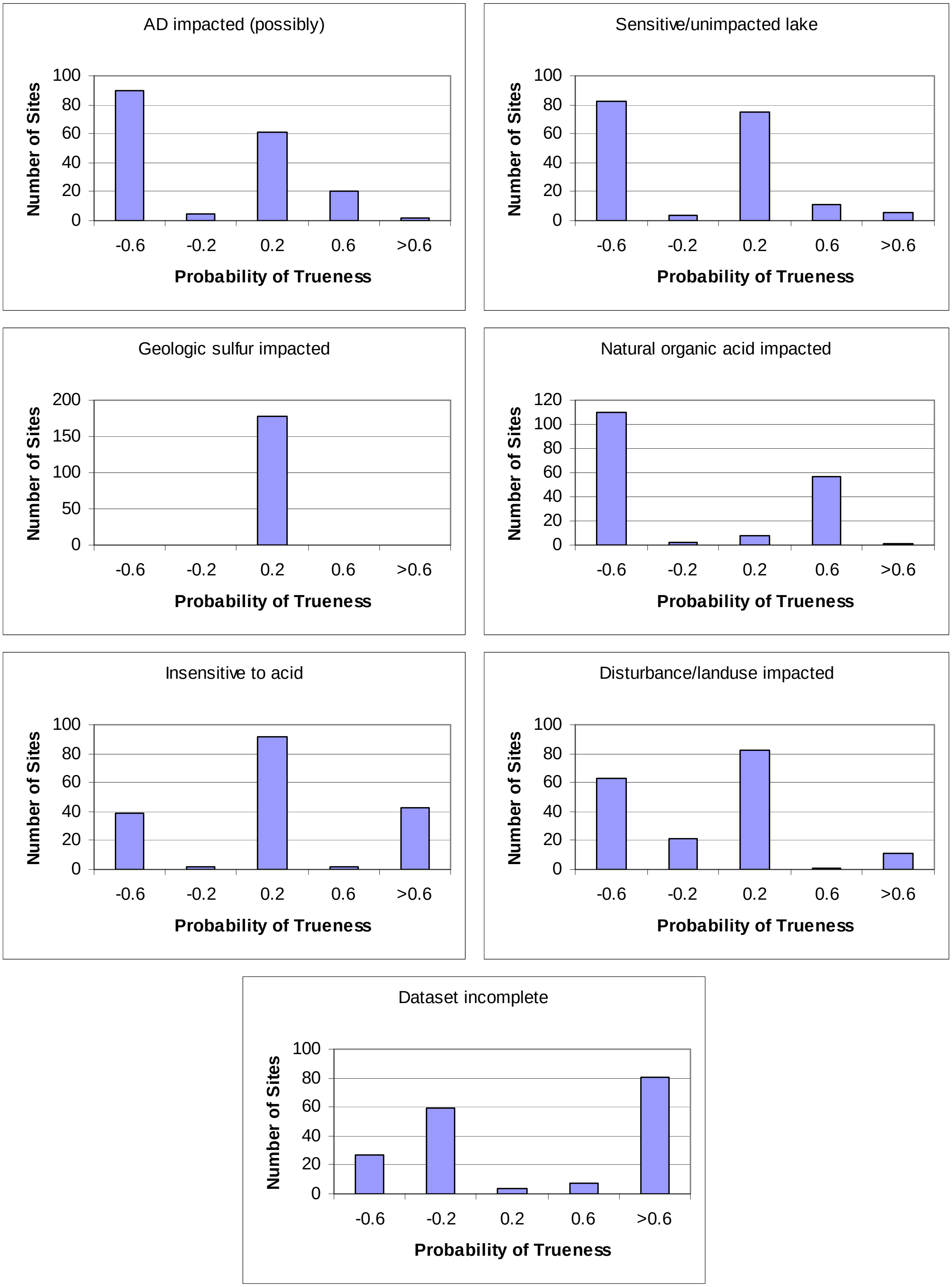
| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 90 | 82 | 0 | 110 | 39 | 63 | 27 |
| -0.59 to -0.20 | 5 | 4 | 0 | 2 | 2 | 21 | 59 |
| -0.19 to 0.20 | 61 | 75 | 178 | 8 | 92 | 82 | 4 |
| 0.21 to 0.60 | 20 | 11 | 0 | 57 | 2 | 1 | 7 |
| 0.61 to 1.00 | 2 | 6 | 0 | 1 | 43 | 11 | 81 |

Of the 117 lakes for which the DSS made an assessment about acid deposition, 95 are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category). Many of these lakes have high ANC values (> 50 μeq/L) and low nitrate concentrations (< 10 μeq/L). Twenty-two lake locations were identified as being acid deposition impacted (true in the 'Acid Deposition Impacted' category); this includes the sites listed in Table 14-6, with the exception of Arctic Lake #2 (SEKI0215) and Arctic Lake #5, and adding Guitar Lake Outlet (SEKI0188). These sites are characterized by low ANC values (≤ 51 μeq/L) and specific conductance values (≤ 12 μS/cm).

Eighty-six lakes are classified as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). Most of these lakes have high ANC (> 50 μeq/L) and high specific conductance values (≥ 15 μS/cm). The DSS did not make a recommendation on 75 lake sites for this category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. The remaining 17 lake locations were found to be sensitive but not impacted (true in the 'Sensitive but Unimpacted' category). Most of the locations in this category have low ANC values (< 50 μeq/L), and all have low specific conductance values (≤ 10 μS/cm), and low base cation concentrations (< 100 μeq/L). This indicates that these locations do not have the buffering capacity to deal with future acid additions. These sites also have low nitrate concentrations (≤ 10 μeq/L) and low sulfate concentrations (< 30 μeq/L), which indicates that they have not yet been impacted by the presence of acidic compounds. The locations are the same as those listed in Table 14-7, with the exception of Emerald Lake (SEKI0225) and Pear Lake (SEKI0233).

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

**Figure 14-6: Charts of DSS Results for Extreme Lake Values - SEKI**



One hundred twelve lakes were found to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted' category). This is due to high buffer capacity as represented by high ANC values (> 50 μeq/L) and low DOC concentrations (≤ 2.2 mg/L). The DSS found that 58 lakes were impacted by natural organic acids (true in the 'Natural Organic Acid Impacted' Category). This is due to a combination of low buffering capacity, represented by low ANC and specific conductance values, slightly acidic pH, and low nitrate and sulfate concentrations. These values indicate that the lakes have been impacted by acid, but nitrogen and sulfur deposition are not the cause. These locations are listed in Table 14-8, with the addition of Summit Lake (SEKI0001) and Mosquito Lake 1 (SEKI0139).

The DSS did not make an assessment on 92 lakes in the 'Insensitive to Acid' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. Forty-five lakes are insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (> 67 μeq/L). The 41 remaining lakes were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category). The ANC values at these locations are below 60 μeq/L. These lakes are listed in Table 14-9, with the addition of Twin Lake (SEKI0261).

Eighty-four lakes were found to not suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). In all of these cases, the nitrate concentration was ≤ 8 μeq/L. For another 82 locations, the DSS did not make a classification for this category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. Twelve lakes were considered by the DSS to be impacted by the effects of disturbance or land use (true in the 'Disturbance or Land Use Impacted' category. These locations are the seven listed above plus Arctic Lake #2 (SEKI0215), Arctic Lake 5 (SEKI0219), Emerald Lake (SEKI0225), Emerald Lake Outflow (SEKI0231), and Lake F11 Outlet (SEKI0371). Each of these locations has a nitrate concentration greater than 12 μeq/L.

*Streams - Average Water Chemistry Values*

Table 14-11 lists the results of the Synthesis DSS for average water chemistry values at streams in Sequoia/Kings Canyon NP and Figure 14-7 represents this data graphically.

**Table 14-11: DSS Results for Average Stream Values - SEKI**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 221 | 217 | 0 | 169 | 15 | 186 | 5 |
| -0.59 to -0.20 | 3 | 2 | 0 | 6 | 6 | 22 | 133 |
| -0.19 to 0.20 | 6 | 20 | 249 | 23 | 58 | 16 | 41 |
| 0.21 to 0.60 | 19 | 10 | 0 | 51 | 1 | 0 | 35 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 169 | 25 | 35 |

Six of the stream sites had only one data parameter for the DSS. Two of these had only a nitrate concentration. The DSS makes no recommendations for any of the categories for these streams except for ‘Acid Deposition Impacted’ and ‘Disturbance or Land Use Impacted’ categories. The other 4 sites had only specific conductance. The DSS makes no recommendations for any of the categories for this stream except for ‘Acid Deposition Impacted’ and ‘Sensitive but Unimpacted’ categories.

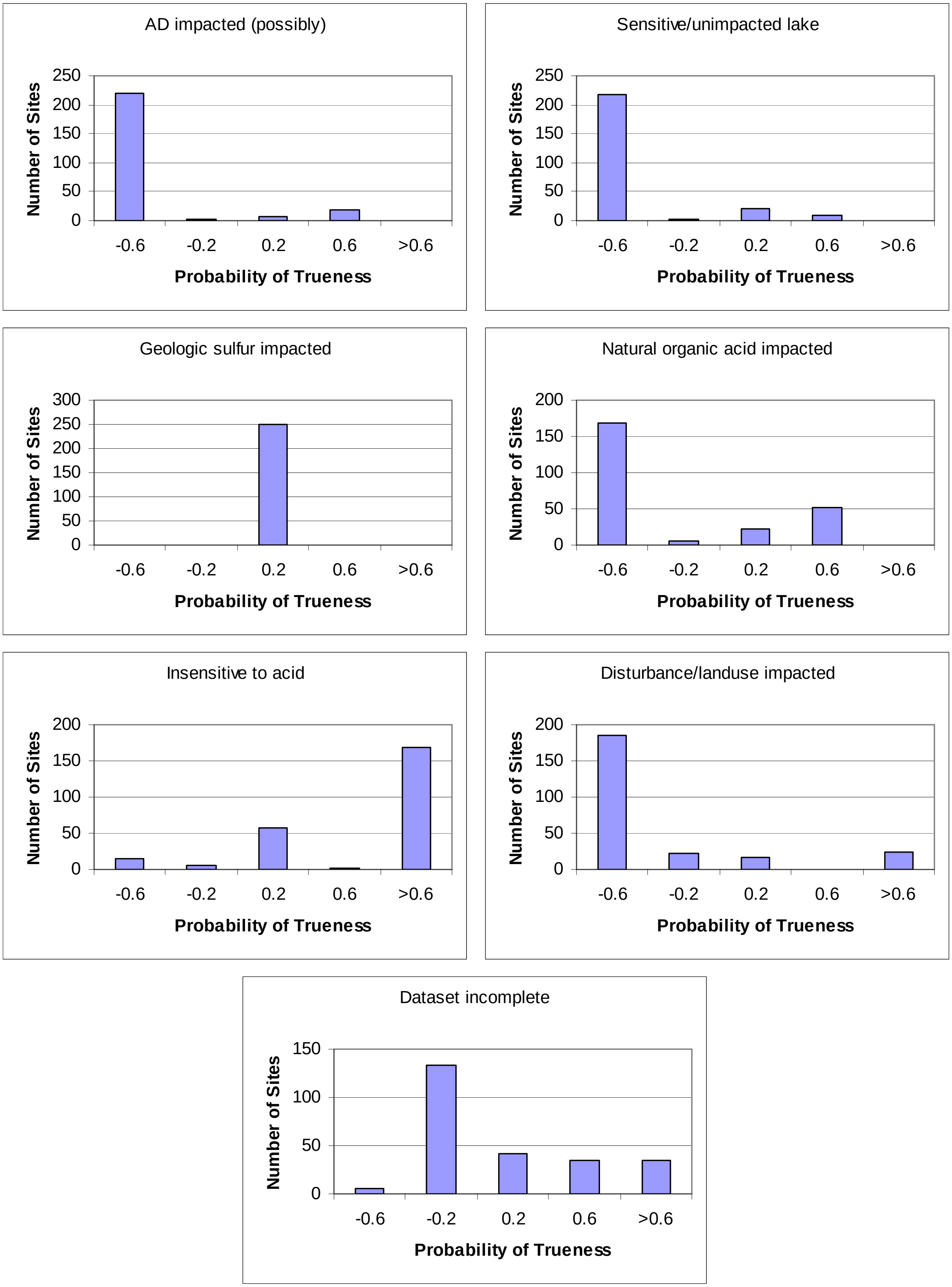
Of the 243 streams for which the DSS made an assessment, 224 were found to not be impacted by acid deposition (false in the ‘Acid Deposition Impacted’ category). Most of the streams are very well buffered, as indicated by high ANC values (> 100 $\mu$eq/L) and high specific conductance (> 20 $\mu$S/cm). The DSS found 19 streams to be impacted by acid deposition (true in the ‘Acid Deposition Impacted’ category). These locations have poor buffering capacity as indicated by low ANC values ($\leq$ 40 $\mu$eq/L) and low specific conductance values (< 15 $\mu$S/cm). Impacted locations are listed in Table 14-12.

**Table 14-12: Streams rated true in the ‘Acid Deposition Impacted’ category.**

| Location ID | Location Name |
|---|---|
| SEKI0013 | Lake P35-1 Inlet #1 |
| SEKI0015 | Lake P35-1 Inlet #2 |
| SEKI0017 | Forrester Lake Inlet #2 |
| SEKI0018 | Forrester Lake Inlet #1 |
| SEKI0021 | Forrester Meadow Outlet |
| SEKI0024 | Forrester Meadow Site C |
| SEKI0026 | Forrester Meadow Site B |
| SEKI0156 | Hitchcock Lake Lower Inlet |
| SEKI0166 | Whitney Creek |
| SEKI0186 | Guitar Lake Inlet #1+ |

| Location ID | Location Name |
|---|---|
| SEKI0187 | Guitar Lake Inlet #1 |
| SEKI0190 | Guitar Lake Inlet #2 |
| SEKI0191 | Guitar Lake Inlet #3 |
| SEKI0192 | Guitar Lake Inlet #6 |
| SEKI0193 | Guitar Lake Inlet #0 |
| SEKI0195 | Guitar Lake Inlet #5 |
| SEKI0214 | Arctic Lake Inlet |
| SEKI0259 | Dorst Creek |
| SEKI0447 | Darwin Canyon Creek |

**Figure 14-7: Charts of DSS Results for Average Stream Values - SEKI**



The DSS rated 219 streams as not being sensitive but unimpaired (false in the 'Sensitive but Unimpaired' category). Most of these streams have high ANC values (> 100 μeq/L), high specific conductance values (> 20 μS/cm), and high base cation concentrations (> 200 μeq/L, indicating high buffering capability. The streams rate as false for this category because they are insensitive to the introduction of acid because of this high buffering capacity. Only 10 streams were identified as sensitive but unimpaired (true in the 'Sensitive but Unimpaired' category). These locations, listed in Table 14-13, have ANC values below 50 μeq/L, specific conductance values below 15 μS/cm, and low nitrogen concentrations (≤ 7 μeq/L), with one exception.

**Table 14-13: Streams rated true in the 'Sensitive but not Impacted' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| SEKI0013 | Lake P35-1 Inlet #1 | SEKI0166 | Whitney Creek |
| SEKI0015 | Lake P35-1 Inlet #2 | SEKI0194 | Guitar Lake Inlet #5 |
| SEKI0017 | Forrester Lake Inlet #2 | SEKI0214 | Arctic Lake Inlet |
| SEKI0018 | Forrester Lake Inlet #1 | SEKI0230 | Emerald Lake |
| SEKI0021 | Forrester Meadow Outlet | SEKI0447 | Darwin Canyon Creek |

With the exception of Emerald Lake and Guitar Lake Inlet #5, all of the locations listed in Table 12-13 are listed as true in both the 'Acid Deposition Impacted' and 'Sensitive but not Impacted' categories. It seems counterintuitive that a single water body can be both 'Acid Deposition Impacted' and 'Sensitive but not Impacted'. There is a reasonable interpretation of these seemingly conflicting categories. These results demonstrate that the model allows for some uncertainty in definitely lumping a lake into one category at the exclusion of all others. The potential for it to be sensitive but unimpacted is due to the fact that there still is fairly high ANC and pH; impact, if it exists, would be gauged to be moderate. The potential for it to be acid deposition impacted is due to nitrate and sulfate values that could well be caused by acid deposition and to ANC that is low enough to have suffered some moderate impact.

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

One hundred seventy-five streams do not have evidence that high dissolved organic carbon appreciably contributed to low ANC or pH (false in the 'Natural Organic Acid Impacted' category). At those sites that have DOC data, the DOC concentration is low (< 5.4 μeq/L). As mentioned above, most of the streams have high buffering capacity, offsetting all acids, including organic acids. The DSS identified 51 streams as impacted by organic acidic sources (true in the 'Natural Organic Acid Impacted' category). With some exceptions, these stream locations are characterized by low buffering capability (low ANC and/or low specific conductance) and low nitrate concentrations (≤ 10 μeq/L). The 51 sites are listed in Table 14-14.

**Table 14-14: Streams rated true in the 'Natural Organic Acid Impacted' category.**

| Location ID | Location Name |
|---|---|
| SEKI0013 | Lake P35-1 Inlet #1 |
| SEKI0015 | Lake P35-1 Inlet #2 |
| SEKI0017 | Forrester Lake Inlet #2 |
| SEK0018I | Forrester Lake Inlet #1 |
| SEKI0020 | Forrester Meadow Site D |
| SEKI0021 | Forrester Meadow Outlet |
| SEKI0024 | Forrester Meadow Site C |
| SEKI0026 | Forrester Meadow Site B |
| SEKI0108 | Big Arroyo |
| SEKI0112 | Middle Fork at Potwisha |
| SEKI0116 | Kaweah River - Main Fork |
| SEKI0158 | Tharps Creek |
| SEKI0161 | South Creek Above Confluence |
| SEKI0166 | Whitney Creek |
| SEKI0170 | South Creek Below Road |
| SEKI0186 | Guitar Lake Inlet #1+ |
| SEKI0192 | Guitar Lake Inlet #6 |
| SEKI0194 | Guitar Lake Inlet #5 |
| SEKI0207 | Kern-Kaweah River |
| SEKI0208 | Marble Fork Below Halstead Creek |
| SEKI0209 | Marble Fork Above Halstead Creek |
| SEKI0213 | Tamarack Meadow |
| SEKI0214 | Arctic Lake Inlet |
| SEKI0230 | Emerald Lake |
| SEKI0238 | Marble Fork Below Campground |
| SEKI0242 | Red Fir Creek |
| SEKI0246 | Marble Fork Above Campground |
| SEKI0247 | Clover Creek |
| SEKI0248 | Kaweah River – Marble Fork |
| SEKI0250 | Clover Creek Below Feeder Stream |
| SEKI0251 | Clover Creek at Feeder Stream |
| SEKI0252 | Clover Creek Above Feeder Stream |
| SEKI0258 | Kern River Near Milestone Creek |
| SEKI0260 | Roaring River |
| SEKI0263 | Sugarloaf Creek – South Fork |
| SEKI0268 | Deadman Canyon Creek |
| SEKI0271 | Roaring River - Ranger Station |
| SEKI0311 | Woods Creek |
| SEKI0317 | Kid Creek |
| SEKI0329 | Kings River - South Fork |
| SEKI0432 | Kings River - South Fork |
| SEKI0433 | Cartridge Creek |
| SEKI0439 | Palisade Creek |
| SEKI0441 | Dusy Branch |
| SEKI0442 | Kings River – Middle Fork |
| SEKI0446 | San Joaquin River - South Fork |
| SEKI0447 | Darwin Canyon |
| SEKI0450 | McGee Canyon Creek |
| SEKI0452 | San Joaquin River - South Fork |
| SEKI0453 | Evolution Creek |
| SEKI0454 | San Joaquin River - South Fork |

The DSS did not make an assessment on 58 stream sites in the 'Insensitive to Acid' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. The majority of streams, 170 locations, are insensitive to acid deposition (true in the 'Insensitive to Acid' category). Indicative of these results are high ANC values (> 100 $\mu$eq/L) and high base cation concentrations (>200 $\mu$eq/L), indicators of high buffering capacity. The remaining 21 sites were found to be sensitive to future acid introductions (false in the 'Insensitive to Acid' category). Streams in this list, displayed in Table 14-15, are characterized by low buffering capacity, as shown by low ANC values (< 50 $\mu$eq/L) and low specific conductance values (< 30 $\mu$S/cm).

**Table 14-15: Streams rated false in the 'Insensitive to Acid' category.**

| Location ID | Location Name |
|---|---|
| SEKI0013 | Lake P35-1 Inlet #1 |
| SEKI0015 | Lake P35-1 Inlet #2 |
| SEKI0017 | Forrester Lake Inlet #2 |
| SEKI0018 | Forrester Lake Inlet #1 |
| SEKI0021 | Forrester Meadow Outlet |
| SEKI0108 | Big Arroyo |
| SEKI0166 | Whitney Creek |
| SEKI0194 | Guitar Lake Inlet #5 |
| SEKI0207 | Kern-Kaweah River |
| SEKI0214 | Arctic Lake Inlet |
| SEKI0230 | Emerald Lake |

| Location ID | Location Name |
|---|---|
| SEKI0258 | Kern River near Milestone Creek |
| SEKI0263 | Sugarloaf Creek – South Fork |
| SEKI0433 | Cartridge Creek |
| SEKI0441 | Dusy Branch |
| SEKI0442 | Kings River – Middle Fork |
| SEKI0447 | Darwin Canyon Creek |
| SEKI0450 | McGee Canyon Creek |
| SEKI0452 | San Joaquin River - South Fork |
| SEKI0453 | Evolution Creek |
| SEKI0454 | San Joaquin River - South Fork |

The DSS reports 208 streams as not impacted due to disturbance or land use purposes (false in the 'Disturbance or Land Use Impacted' category. In all of these cases, the nitrate concentration was not high enough (≤ 9 μeq/L) to indicate a disturbance or land use effect. Twenty-five sites with nitrate concentrations above 14 μeq/L were considered to be impacted by a disturbance or from land use (true in the 'Disturbance or Land Use Impacted' category). The concentration of nitrate at these locations, listed in Table 14-16, is too high to be attributable to nitrogen deposition alone.

**Table 14-16: Stream locations that are true in the 'Disturbance or Land Use Impacted' category.**

| Location ID | Location Name |
|---|---|
| SEKI0056 | Mosquito Creek Near Mouth |
| SEKI0077 | Kaweah River - East Fork |
| SEKI0104 | Ash Mountain Dump |
| SEKI0115 | Chamise Creek |
| SEKI0160 | Commissary Creek Below South Creek |
| SEKI0161 | South Creek Above Confluence |
| SEKI0162 | Commissary Creek Near Marble Fork |
| SEKI0170 | South Creek Below Road |
| SEKI0171 | South Creek Below East Creek |
| SEKI0173 | South Creek Above East Creek |
| SEKI0174 | West Creek Downstream of South Branch |
| SEKI0175 | East Creek |
| SEKI0177 | West Creek Downstream of North Branch |

| Location ID | Location Name |
|---|---|
| SEKI0179 | West Creek Center |
| SEKI0181 | West Creek Upstream |
| SEKI0183 | North Creek Headwaters |
| SEKI1084 | North Creek Below Upper Spray Field |
| SEKI0196 | North Creek Near Little Deer Creek |
| SEKI0213 | Tamarack Meadow |
| SEKI0226 | Cedar Seep Below Spray Field |
| SEKI0228 | Cedar Seep Above No Name Creek |
| SEKI0234 | No Name Creek Above First Creek |
| SEKI0281 | Roaring River Above Sugarloaf Creek |
| SEKI0447 | Darwin Canyon Creek |
| SEKI0449 | Evolution Creek |

The DSS evaluates all of the locations in terms of the completeness of the input data. All of the stream sites with six or all seven DSS components, totaling 138 sites, are reasonably certain to have complete datasets. At the other 111 locations the datasets were less than complete; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Streams - Extreme Water Chemistry Values*

Table 14-17 contains the results of the Synthesis DSS of extreme water chemistry value for streams in Sequoia/Kings Canyon NP. Figure 14-8 includes graphs of the data in this table.

**Table 14-17: DSS Results for Extreme Stream Values - SEKI**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 217 | 209 | 0 | 139 | 25 | 166 | 5 |
| -0.59 to -0.20 | 2 | 5 | 0 | 9 | 7 | 16 | 133 |
| -0.19 to 0.20 | 8 | 24 | 249 | 24 | 58 | 14 | 43 |
| 0.21 to 0.60 | 22 | 11 | 0 | 76 | 0 | 3 | 32 |
| 0.61 to 1.00 | 0 | 0 | 0 | 1 | 159 | 50 | 36 |

Of the 243 streams for which the DSS made an assessment, 219 were found to not be impacted by acid deposition (false in the ‘Acid Deposition Impacted’ category). Most of the streams are very well buffered, as indicated by high ANC values (> 100 μeq/L), high specific conductance (> 20 μS/cm), and high base cation concentrations (> 200 μeq/L). The DSS found 22 streams to be impacted by acid deposition (true in the ‘Acid Deposition Impacted’ category). These locations have poor buffering capacity as indicated by low ANC values (≤ 40 μeq/L) and low specific conductance values (< 15 μS/cm). Impacted locations include those listed in Table 14-12 with the exception of Guitar Lake Inlet #1 (SEKI0187) and Arctic Lake Inlet (SEKI0214) and the addition of five streams: Middle Fork at Potwisha (SEKI0112), Marble Fork at General’s Highway (SEKI0237), Marble Fork at Log Bridge (SEKI0240), Marble Fork Above Campground (SEKI0246), and Red Fir Creek (SEKI0302).

The DSS rated 214 streams as not being sensitive but unimpaired (false in the ‘Sensitive but Unimpaired’ category). Most of these streams have high ANC values (> 100 μeq/L), high specific conductance values (> 20 μS/cm), and high base cation concentrations (> 200 μeq/L), indicating high buffering capability. The streams rate as false for this category because they are insensitive to the introduction of acid because of this high buffering capacity. Only 11 streams were identified as sensitive but unimpaired (true in the ‘Sensitive but Unimpaired’ category). These locations have ANC values at or below 40 μeq/L and specific conductance values below 15 μS/cm. The locations include those listed in Table 14-13, with the exception of

Emerald Lake (SEKI0230) and the addition of Marble Fork at General's Highway (SEKI0237) and Marble Fork above Campground (SEKI0246).

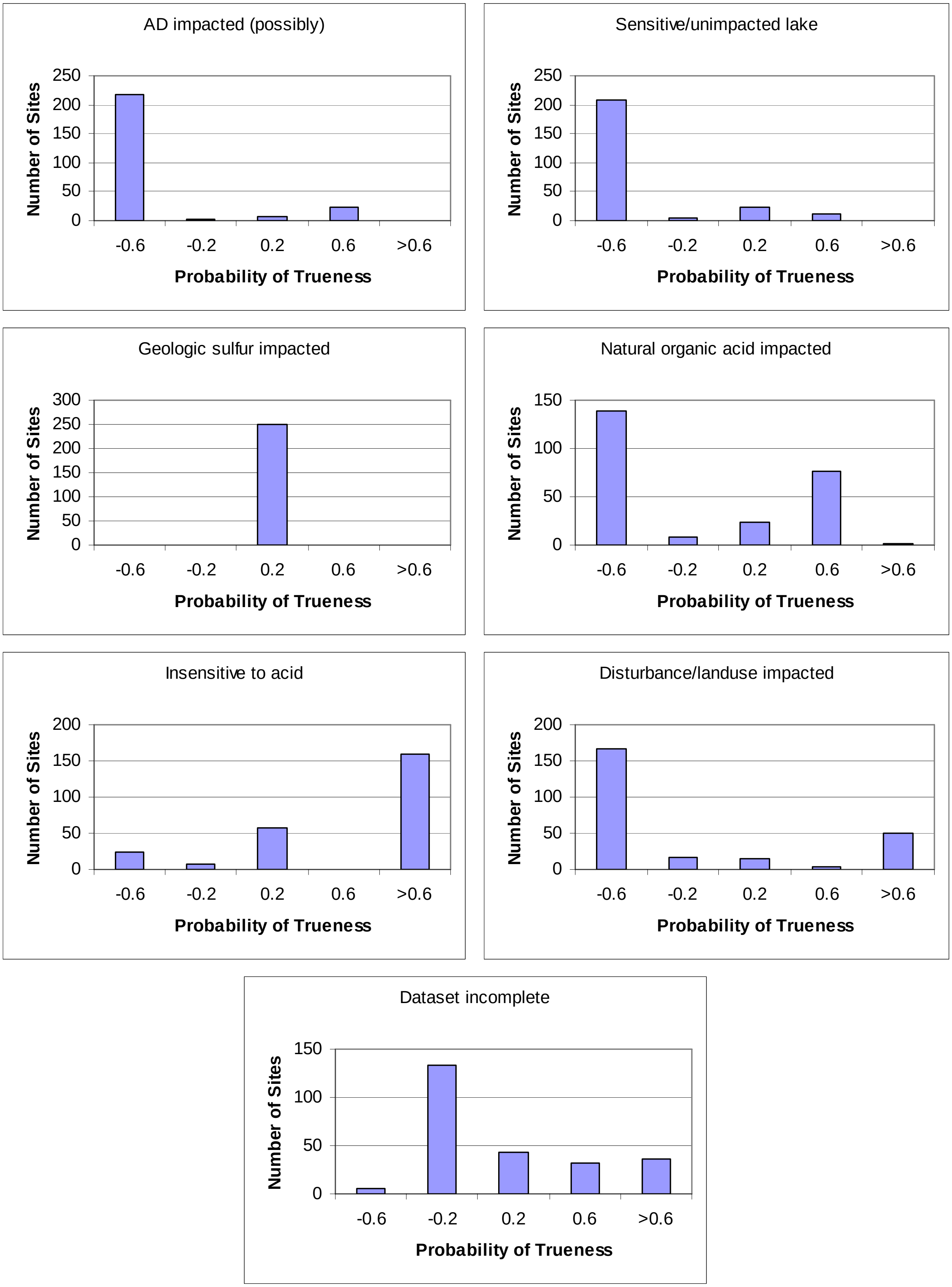
The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

One hundred forty-eight streams do not have evidence that high dissolved organic carbon appreciably contributed to low ANC or pH (false in the 'Natural Organic Acid Impacted' category). Most of these streams have high buffering capacity, indicated by high ANC values (≥ 100 μeq/L) and high base cation concentrations (≥ 100 μeq/L). The DSS identified 77 streams as impacted by organic acidic sources (true in the 'Natural Organic Acid Impacted' category). With some exceptions, these stream locations are characterized by low buffering capability (low ANC and/or low specific conductance) and either low nitrate concentrations (≤ 10 μeq/L) or very high nitrate concentrations (≥ 100 μeq/L). The sites include the locations listed in Table 14-14 plus 26 additional sites listed in Table 14-18.

**Table 14-18: Streams rated as true in the 'Natural Organic Acid Impacted' category for extreme water chemistry values only.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| SEKI0002 | Soda Springs Creek | SEKI0205 | Marble Fork Above Suwannee Creek |
| SEKI0003 | Hunter Creek | SEKI0222 | Halstead Creek Below No Name Creek |
| SEKI0005 | Kaweah River - South Fork | SEKI0224 | Halstead Creek Above No Name Creek |
| SEKI0049 | Spring Creek Near Mouth | SEKI0226 | Cedar Seep Below Spray Field |
| SEKI0055 | Mosquito Creek | SEKI0229 | No Name Creek Above Cedar Seep |
| SEKI0056 | Mosquito Creek Near Mouth | SEKI0237 | Marble Fork at General's Highway |
| SEKI0100 | Kaweah River – Main Stem | SEKI0240 | Marble Fork at Log Bridge |
| SEKI0115 | Chamise Creek | SEKI0254 | Clover Creek Below Outcrop |
| SEKI0120 | Marble Fork Below Potwisha Bridge | SEKI0290 | Roaring River Falls |
| SEKI0128 | Kaweah River – Middle Fork | SEKI0294 | Kings River - South Fork |
| SEKI0157 | Log Creek | SEKI0295 | Granite Creek |
| SEKI0163 | Marble Fork Below Commissary Creek | SEKI0297 | Kings River - South Fork |
| SEKI0164 | Marble Fork Above Commissary Creek | SEKI0305 | Kings River - South Fork |

**Figure 14-8: Charts of DSS Results for Extreme Stream Values - SEKI**



The DSS did not make an assessment on 58 stream sites in the 'Insensitive to Acid' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category. The majority of streams, 159 locations, are insensitive to acid deposition (true in the 'Insensitive to Acid' category). Indicative of these results are high ANC values (> 100 μeq/L) and high base cation concentrations (> 200 μeq/L), indicators of high buffering capacity. The remaining 32 sites were found to be sensitive to future acid introductions (false in the 'Insensitive to Acid' category). Streams in this list are characterized by low buffering capacity, as shown by low ANC values (< 50 μeq/L) and low specific conductance values (< 30 μS/cm). These locations are the 21 included in Table 14-15 plus 11 additional sites.

**Table 14-19: Streams rated false in the 'Insensitive to Acid' category for extreme water chemistry values only.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| SEKI0100 | Kaweah River - Main Stem | SEKI0226 | Cedar Seep Below Spray Field |
| SEKI0115 | Chamise Creek | SEKI0237 | Marble Fork at General's Highway |
| SEKI0128 | Kaweah River - Middle Fork | SEKI0246 | Marble Fork Above Campground |
| SEKI0157 | Log Creek | SEKI0248 | Kaweah River - Marble Fork |
| SEKI0158 | Tharps Creek | SEKI0274 | Roaring River Above Ranger Station |
| SEKI0161 | South Creek Above Confluence | | |

The DSS reports 182 streams as not impacted due to disturbance or land use purposes (false in the 'Disturbance or Land Use Impacted' category. In all of these cases, the nitrate concentration was not high enough (≤ 9 μeq/L) to indicate a disturbance or land use effect. Fifty-three sites with nitrate concentrations above 13 μeq/L were considered to be impacted by a disturbance or from land use (true in the 'Disturbance or Land Use Impacted' category). The concentration of nitrate at these locations is too high to be attributable to nitrogen deposition alone. These include the 25 sites listed in Table 14-16 and 28 additional sites listed in Table 14-20.

**Table 14-20: Stream locations that are true in the 'Disturbance or Land Use Impacted' category.**

| | |
|---|---|
| Franklin Creek | Kaweah River - East Fork Above SEKI Boundary |
| Franklin Creek Near Mouth | Atwell Creek Above Mineral King Highway |
| Squirrel Creek | Kaweah River - Main Stem at Boundary |
| Kaweah River at Three Rivers | Kaweah River- Main Stem Below Headquarters |
| Kaweah River- East Fork Below Eagle Creek | Kaweah River – Middle Fork Above Buckeye Bridge |
| Mosquito Creek | Log Creek |
| Kaweah River - East Fork Above Monarch Creek | Tharps Creek |
| Kaweah River - East Fork Below Mosquito Creek | Guitar Lake Inlet #1 |
| Kaweah River - East Fork Below Mosquito Creek | Guitar Lake Inlet #5 |
| Kaweah River - East Fork Overflow | Arctic Lake Inlet |
| Monarch Creek Near Hammond | No Name Creek Below Cedar Seep |
| Monarch Creek Near Mouth | Emerald Lake |
| East Fork Kaweah River Below Monarch Creek | Roaring River Falls |
| Redwood Creek Above Mineral King Highway | Granite Creek |

### Analysis

## Conclusion

The data for Sequoia and Kings Canyon NP's used in this report tended to be recent, with 36% of samples collected in the 1990's. Lakes tended to have either data only for specific conductance and pH or to have data for all parameters used by the DSS except for DOC, with about 48% of lakes having 5 or more parameters used by the DSS. ANC concentrations for lakes seemed to have a normal distribution, with numerous lakes having ANC less than 50 ueq/L. DSS results indicated potential impact from acidic deposition in about 13% of lake samples and sensitivity to acidic deposition in as many as 22% of lake samples. Impacts from natural organic acids were judged to be possible in 60 lake samples (33%) but only 27 of these samples included data for DOC, so results should be considered tentative. Impacts from disturbance or land use seem likely in seven lakes. Geologic sulfur does not seem to impact any of the lakes sampled.

Streams in Sequoia and Kings Canyon NP tend to have 6 or more parameters used by the DSS (53% of samples) or to have only specific conductance, pH, ANC, and nitrate. DSS results indicated potential impact from acidic deposition in about 7% of stream samples and sensitivity to acidic deposition in as many as 8% of stream samples. Impacts from natural organic acids were judged to be possible in 51 stream samples (20%) but only 5 of these samples included data for DOC, so results should be considered tentative. Impacts from disturbance or land use seem likely in 25 streams. Geologic sulfur does not seem to impact any of the lakes sampled.

# Chapter 15 - Yosemite National Park

## Background

### Description

Yosemite National Park is located in the central Sierra Nevada of California and lies 150 miles east of San Francisco. The 750,000-acre, 1,200 square-mile Park contains thousands of lakes and ponds, approximately 3,200 lakes and ponds (greater than 100 square meters), two reservoirs, and 1,700 miles of streams. Within the boundaries of Yosemite flow the headwaters and significant stream reaches of the Tuolumne and Merced Rivers, both of which are tributaries of the San Joaquin River basin.

Yosemite National Park experiences a Mediterranean climate with typically long, hot summers and mild winters. Precipitation amounts vary from 36 inches (915 mm) at 4,000 feet (1200 m) elevation to 50 inches (1200 mm) at 8,600 feet (2600 m). Most of the precipitation falls as snow between October and April. From May through September, precipitation is infrequent.

### Deposition

YOSE is potentially exposed to pollutants transported from the San Joaquin Valley and other areas. Emission sources within the San Joaquin Valley Air Basin account for about 14% of total statewide emissions (Alexis et al., 1999). These emissions derive from a number of moderate-sized urban areas. Since 1980, population growth in the San Joaquin Valley has been more rapid than in other parts of California, partially offsetting the effects of emission-control programs (Alexis et al., 1999).

Air pollution is currently recognized as one of the most significant threats to the resources of the Sierra Nevada. Sources of pollutants that transform into acidic deposition include motor vehicle emissions, industrial emissions, and various forms of agricultural activities. While chronic acidification is not a problem at present, there are episodes when the capacity of lakes and streams to neutralize acids gets reduced. This is often measured during the onset of snowmelt and during late summer rainstorms.

The monitoring station for collection of precipitation volume and chemistry has been operating as part of the NADP/NTN network since 1981. It is in Hodgden Meadow at an elevation of 1,800 m. Average annual precipitation at the NADP station was 110 cm/yr between 1982 and 1991.

**Figure 15-1: Sulfate wet deposition at Hodgdon Meadows NADP site in Yosemite NP, 1981-2003.**

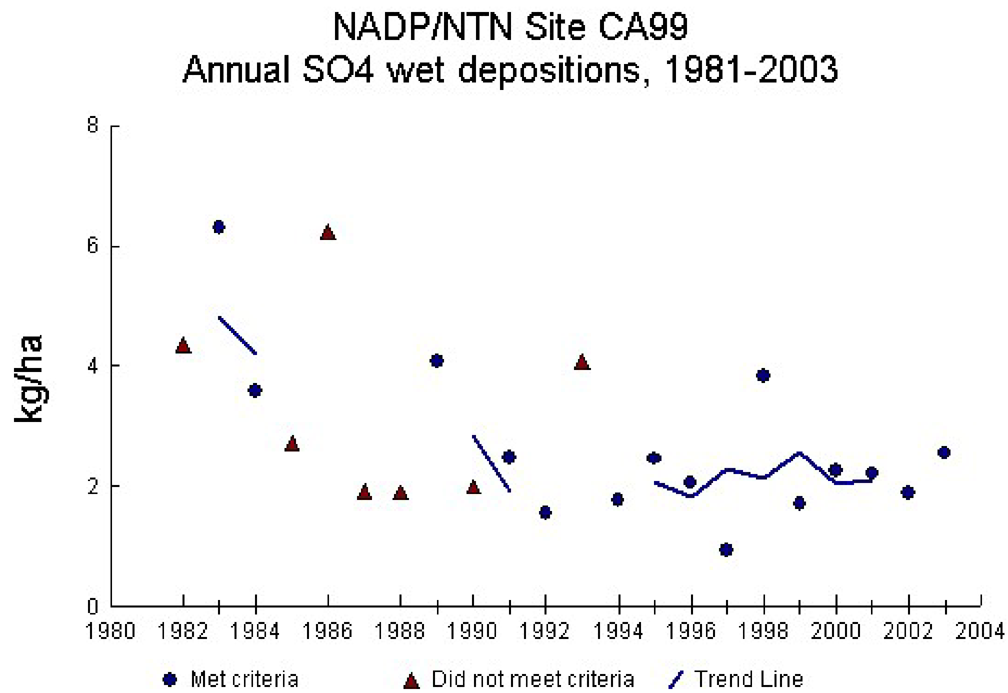



**Figure 15-2: Inorganic N wet deposition at Hodgdon Meadow NADP site in Yosemite NP, 1981-2003.**

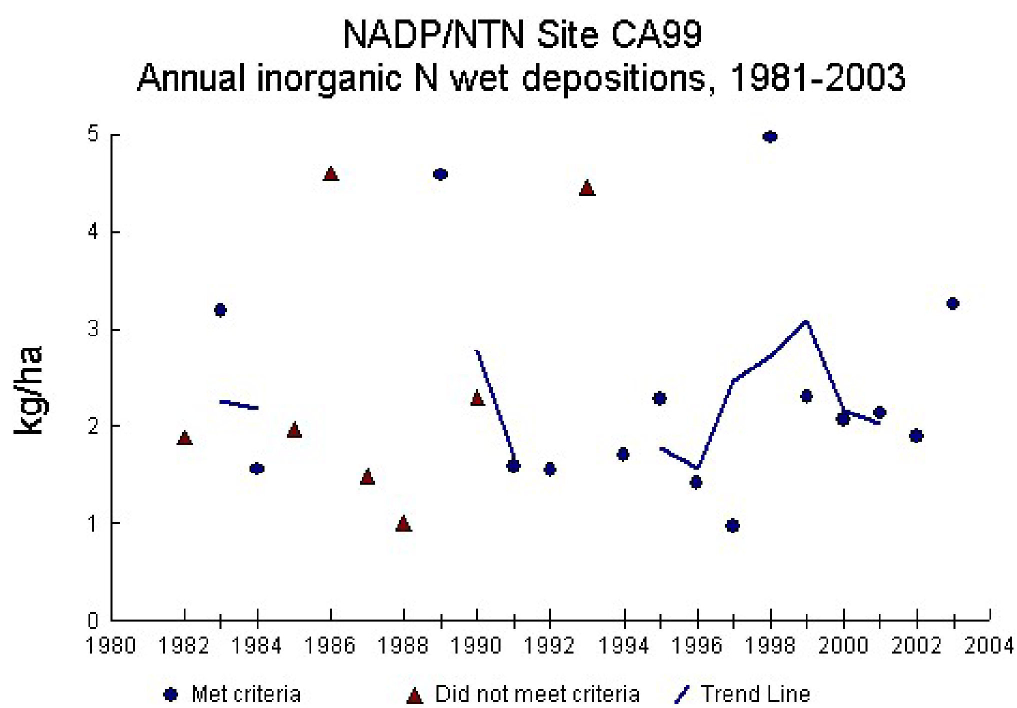


Figure 15-1 shows annual wet sulfate deposition in YOSE for the period 1981 to 2003. Deposition rates were primarily between 1.8 and 2.4 kg/ha/yr as $SO_4^{2-}$, with individual years ranging as high as 6 kg/ha/yr. There is no discernible long-term trend for sulfate deposition at this location but there was a decrease during 1981-1986.

Annual wet inorganic nitrogen deposition for the period 1981 to 2003 was primarily between 1.0 and 2.6 kg/ha/yr, although deposition rates were as high as 5.0 kg/ha/yr (Figure 15-2). There is no clear no term trend.

## Water Quality

There are about 268 lakes within the park and 92 rivers and streams within YOSE. Water quality surveys conducted during the early 1980s by the U.S. Geological Survey and in 1985 by the Environmental Protection Agency indicated that most waters sampled in YOSE represent relatively pristine water quality conditions. An inventory of water quality performed by the National Park Service indicated pristine conditions in many parts of the park, with some water quality degradation in areas of high visitor use.

The result of surface water quality data retrievals for YOSE from five national data bases were summarized by NPS-WRD (1994). The Storage and Retrieval Data Base Management System (STORET) covered 109 water quality sampling stations within the park boundary; 58 monitoring stations had pH ≤ 6.5 and total alkalinity at 11 lake monitoring stations were below 200 μeq/L. The STORET database includes 10 lakes in YOSE that had reported conductivity ≤ 5 μS/cm. Several had reported conductivity of only 1 μS/cm. These data suggest that YOSE contains a number of highly dilute and presumably acid-sensitive lakes.

A 40-km stretch of the Merced River was studied by Hoffman et al. (1976) to evaluate its water quality. pH values were generally in the range of 6.5 to 7. Specific conductance was generally above 10 μS/cm. The authors reported ANC values of in the range of about 40 to 500 μeq/L.

The surface water draining granitic bedrock in YOSE shows considerable variation in chemical composition despite the fact that bedrock chemistry is relatively homogeneous. Other geological factors, including jointing of the bedrock and the distribution of glacial till, appear to exert strong controls on water chemistry (Clow et al. 1996). The presence of glacial till can exert an important control on the base cation concentrations and therefore the ANC of surface waters. The quantity of soil and other types of surficial materials in the watershed are important determinants of drainage water chemistry. This is largely because such materials can slow the movement of water through a watershed, increasing its residence time, and provide additional opportunities for weathering products to be contributed to drainage water. Also, because till can contain considerable amounts of fine material, it provides abundant mineral surfaces with which the drainage water can react (Peters and Murdoch 1985, Newton et al. 1987, Clow et al. 1996).

The most acid-sensitive lakes in and near YOSE, having ANC less than about 30 μeq/L, had very low concentrations of base cations (about 20 to 35 μeq/L) and low DOC (< 2 mg/L). All are presumably highly-sensitive to chronic, and especially episodic, acidification if sulfur or nitrogen deposition increased substantially.

## Aquatic Chemistry Data and DSS Results

### Horizon Report

The Horizon report was released for Yosemite NP in September 1994. The report contains information on 123 water bodies in the parks. More water bodies exist, but were not sampled; only 13% of the 268 lakes in the park were sampled. The vast majority (89%) of water bodies in the report contained data relevant to the DSS. The report details 35 lakes, 85 streams, and 3 springs in YOSE. Table 15-1 lists the number of sites that have data for each DSS component. With the exception of DOC, data is relatively complete for both lakes and streams.

**Table 15-1: Chemistry Component Summary - YOSE**

| | Total | Lakes | Streams | Springs |
|---|---|---|---|---|
| Number | 123 | 35 | 85 | 3 |
| Conductance | 97 | 33 | 62 | 2 |
| pH | 107 | 33 | 72 | 2 |
| ANC | 97 | 33 | 62 | 2 |
| DOC | 12 | 11 | 1 | 0 |
| Nitrate | 109 | 33 | 74 | 2 |
| Base Cations | 104 | 31 | 71 | 2 |
| Sulfate | 104 | 31 | 71 | 2 |

Only 6% of lake sites had no data elements used by the DSS, compared to 13% of stream sites. For those sites with data, the data is substantially complete. 89% of lake sites and 72% of stream sites contained six or more of the data elements (Table 15-2). As is typical at the parks studied, DOC data is fairly limited. With the exception of DOC data a standard set of chemical analyses were performed on water samples taken in YOSE.

Of the 119 sites that had any data collection, including parameters not used by the DSS, 18 sites were last sampled in the 1970s, 75 in the 1980s, and 16 in the 1990s. The data is relatively old in ths parks, with 87% of sites last sampled before 1990. No lakes were sampled during the 1990s, while only 15% of streams were last sampled during this decade. Most of the data in this report are 15 years old or older and may not indicate current water chemistry conditions.  Additional sampling should take place so that the DSS can have up to date data for making recommendations.

**Table 15-2: Number of Elements Summary - YOSE**

| # of Elements | Total | Lakes | Streams | Others |
|---|---|---|---|---|
| 0 | 14 | 2 | 11 | 1 |
| 1 | 2 | 0 | 2 | 0 |
| 2 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 |
| 4 | 13 | 2 | 11 | 0 |
| 5 | 0 | 0 | 0 | 0 |
| 6 | 82 | 20 | 60 | 2 |
| 7 | 12 | 11 | 1 | 0 |

Of the 97 locations that had alkalinity data, sampling occurred only once at 56% of them. At these locations, the mean and extreme ANC values are the same. Alkalinity results were based on more than 10 samples at only 8% of all locations. More frequent future sampling will aide in gaining a more robust data set for entry into the DSS.

## ANC Results

One of the parameters captured during data extraction is alkalinity, which is a measure of how well the water body can buffer additions of acid to it. A standard calculation of alkalinity is ANC or acid neutralization capacity, measured in microequivalents per liter (μeq/L). Lower ANC values, specifically those below 50 μeq/L, indicate that a water body is potentially sensitive to future additions of acid. Anthropogenic impacts are not necessarily the cause of low ANC values. Some waters are naturally low in ANC. The DSS uses ANC with other factors to determine acid impact.

The spreadsheet contains two ANC values for each location. The mean ANC value indicates average ANC conditions for a water body. The minimum ANC value indicates the least amount of buffering capacity found at a location and intends to denote a worst case scenario for that water body.

### *Mean ANC*

Of the 97 sampling locations which contained data for ANC calculations, 19% had a mean ANC below 50 μeq/L, including 2 sites that had means less than or equal to 25 μeq/L. The locations with mean ANC below 50 μeq/L are listed below (Table 15-3):

**Table 15-3: Locations with mean ANC below 50 $\mu$eq/L - YOSE**

| Site Code | Location Name | ANC ($\mu$eq/L) |
|---|---|---|
| YOSE0121 | (No Name) | 15.6 |
| YOSE0072 | Nelson Lake | 20.0 |
| YOSE0025 | (No Name) | 25.1 |
| YOSE0081 | Lower Cathedral Lake | 28.0 |
| YOSE0118 | (No Name) | 29.2 |
| YOSE0120 | (No Name) | 33.2 |
| YOSE0104 | Roosevelt Lake | 39.0 |
| YOSE0026 | Merced River above Washburn Lake | 40.0 |
| YOSE0030 | Washburn Lake | 40.0 |
| YOSE0068 | Upper Fletcher Lake | 40.0 |
| YOSE0070 | Upper Sunrise Lake | 40.0 |
| YOSE0077 | Tenaya Lake | 40.0 |
| YOSE0091 | Harden Lake | 40.0 |
| YOSE0092 | Ten Lake No. 2 | 40.0 |
| YOSE0097 | Lower Young Lake | 40.0 |
| YOSE0065 | Vogelsang Lake | 47.2 |
| YOSE0066 | Fletcher Creek below Vogelsang High Sierra Camp | 50.0 |
| YOSE0069 | Fletcher Creek above Fletcher Lake | 50.0 |

Figure 15-3 contains a graph of the frequency distribution of mean ANC values in Yosemite National Park.

### *Minimum ANC*

Of the 97 sampling locations which contained data for ANC calculations, 24% had minimum ANCs below 50 $\mu$eq/L, including 4 locations that had a minimum value less than or equal to 25 $\mu$eq/L. These locations are listed in Table 15-4.

Figure 15-4 contains a graph of the frequency distribution of minimum ANC values in Yosemite National Park.

**Figure 15-3: Frequency Distribution of Mean ANC Values - YOSE**

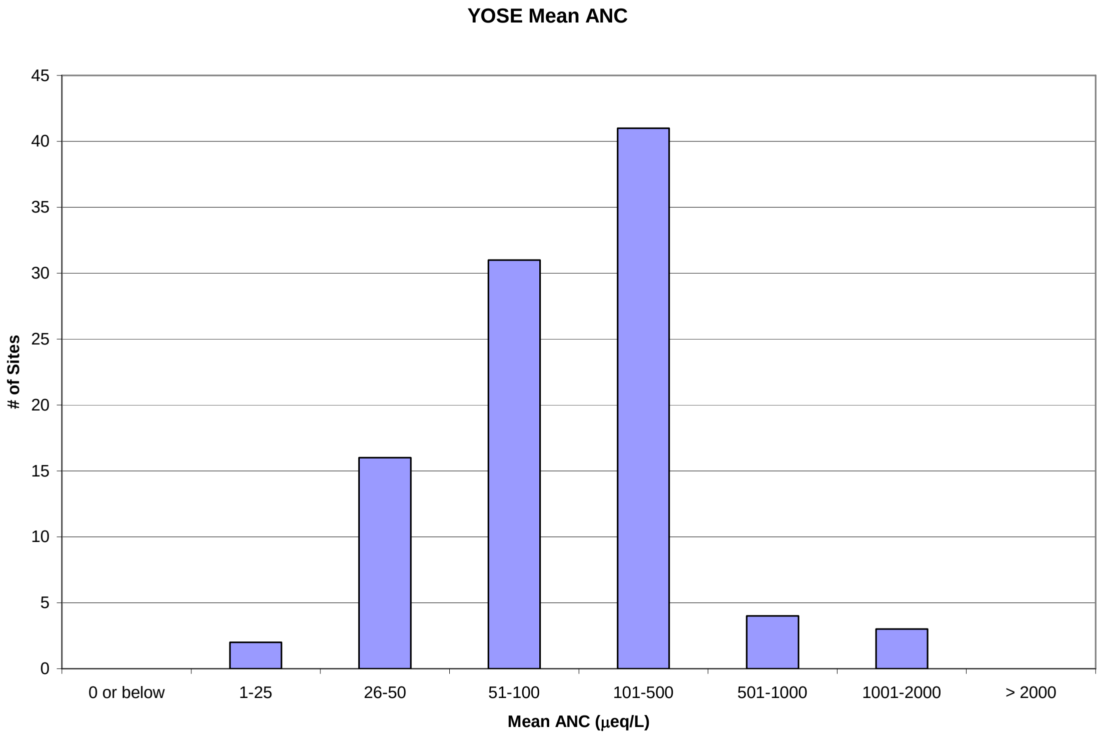



**Figure 15-4: Frequency Distribution of Minimum ANC Values - YOSE**

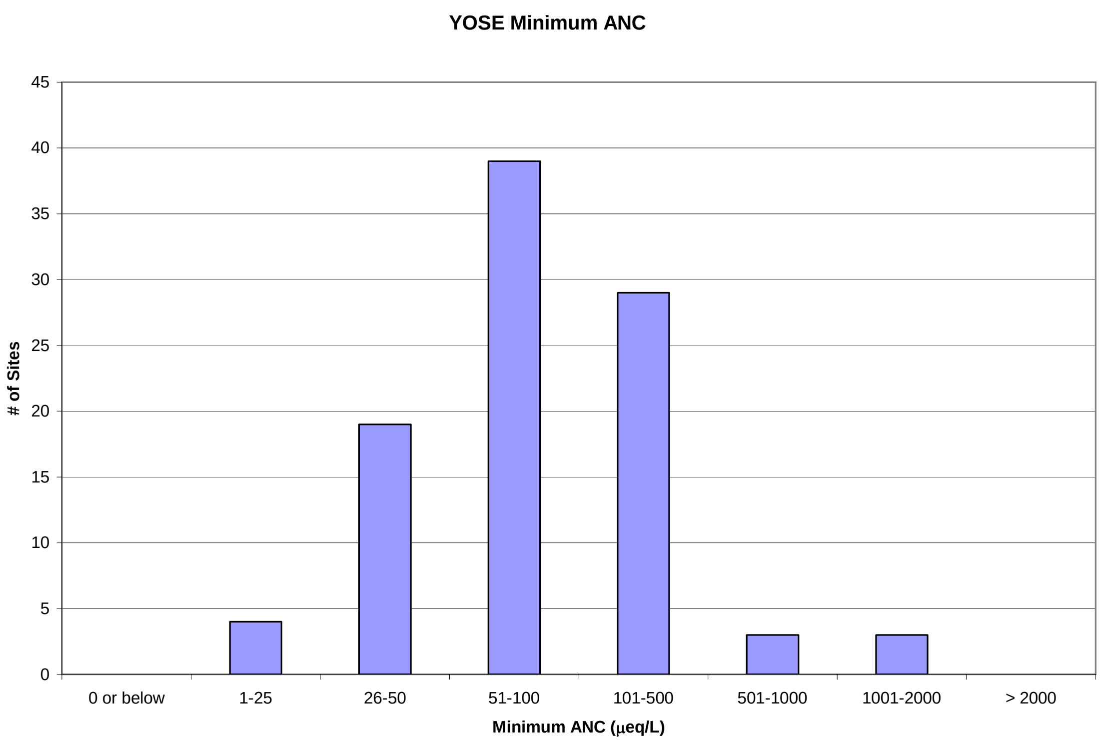


**Table 15-4: Locations with minimum ANC below 50 $\mu$eq/L - YOSE**

| Site Code | Location Name | ANC ($\mu$eq/L) |
|---|---|---|
| YOSE0121 | (No Name) | 15.6 |
| YOSE0081 | Lower Cathedral Lake | 16.0 |
| YOSE0047 | Merced River at Happy Isles Bridge near Yosemite | 20.0 |
| YOSE0072 | Nelson Lake | 20.0 |
| YOSE0025 | (No Name) | 25.1 |
| YOSE0118 | (No Name) | 29.2 |
| YOSE0120 | (No Name) | 33.2 |
| YOSE0104 | Roosevelt Lake | 39.0 |
| YOSE0026 | Merced River above Washburn Lake | 40.0 |
| YOSE0030 | Washburn Lake | 40.0 |
| YOSE0040 | Merced River at El Capitan Bridge near Yosemite Village | 40.0 |
| YOSE0048 | Merced River at Happy Isles Bridge | 40.0 |
| YOSE0051 | Merced River above Sunrise Creek | 40.0 |
| YOSE0068 | Upper Fletcher Lake | 40.0 |
| YOSE0069 | Fletcher Creek above Fletcher Lake | 40.0 |
| YOSE0070 | Upper Sunrise Lake | 40.0 |
| YOSE0077 | Tenaya Lake | 40.0 |
| YOSE0086 | Tuolumne River at Tuolumne Meadows | 40.0 |
| YOSE0091 | Harden Lake | 40.0 |
| YOSE0092 | Ten Lake No. 2 | 40.0 |
| YOSE0097 | Lower Young Lake | 40.0 |
| YOSE0065 | Vogelsang Lake | 47.2 |
| YOSE0066 | Fletcher Creek below Vogelsang High Sierra Camp | 50.0 |

## Aquatic Chemistry DSS Results

The Aquatic Chemistry DSS combines the water chemistry data extracted from the Horizon reports with the location of the park in one of five regions to make recommendations about the present and future impact of acidity on water bodies. For each sampling site in the park, average values and extreme values of the water quality parameters were extracted and processed in the DSS. The extreme values would represent the most acid deposition sensitive conditions for the water body.

### *Lakes - Average Water Chemistry Values*

Table 15-5 contains the results of the Synthesis DSS for average values of water chemistry parameters in lakes in YOSE and Figure 15-5 includes graphical representations of this data.

All of the lake sites had at least 4 data parameters for the DSS. The DSS was able to make recommendations with a reasonable degree of certainty for all of the categories for these lakes.

**Table 15-5: DSS Results for Average Lake Values - YOSE**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 14 | 12 | 0 | 14 | 16 | 32 | 11 |
| -0.59 to -0.20 | 2 | 2 | 0 | 0 | 4 | 1 | 20 |
| -0.19 to 0.20 | 4 | 5 | 33 | 0 | 0 | 0 | 2 |
| 0.21 to 0.60 | 10 | 9 | 0 | 19 | 2 | 0 | 0 |
| 0.61 to 1.00 | 3 | 5 | 0 | 0 | 11 | 0 | 0 |

Of the 33 lakes for which the DSS made an assessment about acid deposition, 16 are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category). These lakes have high ANC, low nitrate concentrations, and relatively low sulfate concentrations. Eleven lakes had a nitrate concentration of less than 1 μeq/L and 12 lakes had a sulfate concentration less than 20 μeq/L. The DSS identified 13 lakes as acid deposition impacted (true in the 'Acid Deposition Impacted category') (Table 15-6). These lakes are characterized by low ANC (< 50 μeq/L), low specific conductance (< 10 μS/cm), and few base cations (< 100 μeq/L). Low specific conductance suggests that the lake may already have been impacted by acid deposition (Sullivan et al., in review).

**Table 15-6: YOSE lake locations rated true in the 'Acid Deposition Impacted' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0030 | Washburn Lake | YOSE0091 | Harden Lake |
| YOSE0065 | Vogelsang Lake | YOSE0092 | Ten Lake Number 2 |
| YOSE0068 | Upper Fletcher Lake | YOSE0104 | Roosevelt Lake |
| YOSE0070 | Upper Sunrise Lake | YOSE0118 | (No Name) |
| YOSE0072 | Nelson Lake | YOSE0120 | (No Name) |
| YOSE0077 | Tenaya Lake | YOSE0121 | (No Name) |
| YOSE0081 | Lower Cathedral Lake | | |

The DSS classified 14 lakes as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). This is primarily due to high ANC values. Fourteen other lakes sites were classified as sensitive but not impacted (true in the 'Sensitive but Unimpacted' category) (Table 15-7). They were identified by low ANC (< 50 μeq/L), low specific conductance (< 10 μS/cm), and few base cations (< 100 μeq/L). Twelve lakes were found to be true in both the 'Acid Deposition Impacted' and 'Sensitive but Unimpacted' categories.

It seems counterintuitive that a single water body can be both 'Acid Deposition Impacted' and 'Sensitive but not Impacted'. There is a reasonable interpretation of these seemingly conflicting categories. These results demonstrate that the model allows for some uncertainty in definitely lumping a lake into one category at the exclusion of all others. The potential for it to be sensitive but unimpacted is due to the fact that there still is fairly high ANC and pH; impact, if it exists, would be gauged to be moderate. The potential for it to be acid deposition impacted is due to nitrate and sulfate values that could well be caused by acid deposition and to ANC that is low enough to have suffered some moderate impact.

**Table 15-7: YOSE lake locations rated true in the 'Sensitive but Unimpacted' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0030 | Washburn Lake | YOSE0091 | Harden Lake |
| YOSE0065 | Vogelsang Lake | YOSE0092 | Ten Lake Number 2 |
| YOSE0068 | Upper Fletcher Lake | YOSE0097 | Lower Young Lake |
| YOSE0070 | Upper Sunrise Lake | YOSE0104 | Roosevelt Lake |
| YOSE0072 | Nelson Lake | YOSE0118 | (No Name) |
| YOSE0077 | Tenaya Lake | YOSE0120 | (No Name) |
| YOSE0081 | Lower Cathedral Lake | YOSE0121 | (No Name) |

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS found 14 lakes to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted' category). This is due to the low levels of DOC found in the samples (< 2.0 mg/L). A majority of lake locations, 19, were considered to be impacted by natural organic acid (true in the 'Natural Organic Acid Impacted' category). They are listed in Table 15-8. These locations have acidic conditions due low buffering capacity, as indicated by low specific conductance values (< 10 μS/cm), and low values of nitrate and sulfate.

**Table 15-8: YOSE lake locations rated true in the 'Natural Organic Acid Impacted' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0016 | Ostrander Lake | YOSE0083 | May Lake |
| YOSE0030 | Washburn Lake | YOSE0084 | Lukens Lake |
| YOSE0031 | Washburn Lake above Lewis Creek | YOSE0090 | Dog Lake |
| YOSE0055 | Merced Lake | YOSE0091 | Harden Lake |
| YOSE0068 | Upper Fletcher Lake | YOSE0092 | Ten Lake Number 2 |
| YOSE0070 | Upper Sunrise Lake | YOSE0093 | Gaylor Lake |
| YOSE0072 | Nelson Lake | YOSE0097 | Lower Young Lake |
| YOSE0077 | Tenaya Lake | YOSE0109 | Lower McCabe Lake |
| YOSE0080 | Elizabeth Lake | YOSE0115 | Benson Lake |
| YOSE0081 | Lower Cathedral Lake | | |

Thirteen lakes are insensitive to acid (true in the 'Insensitive to Acid' category). These lakes would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These lakes have high ANC values (>60 μeq/L). The other 20 lake locations were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category). These locations had ANC values below 60 μeq/L, conductance values under 10 μS/cm, and base cation concentrations under 100 μeq/L. The sensitive lake locations are listed in Table 15-9.

**Figure 15-5: Charts of DSS Results for Average Lake Values - YOSE**

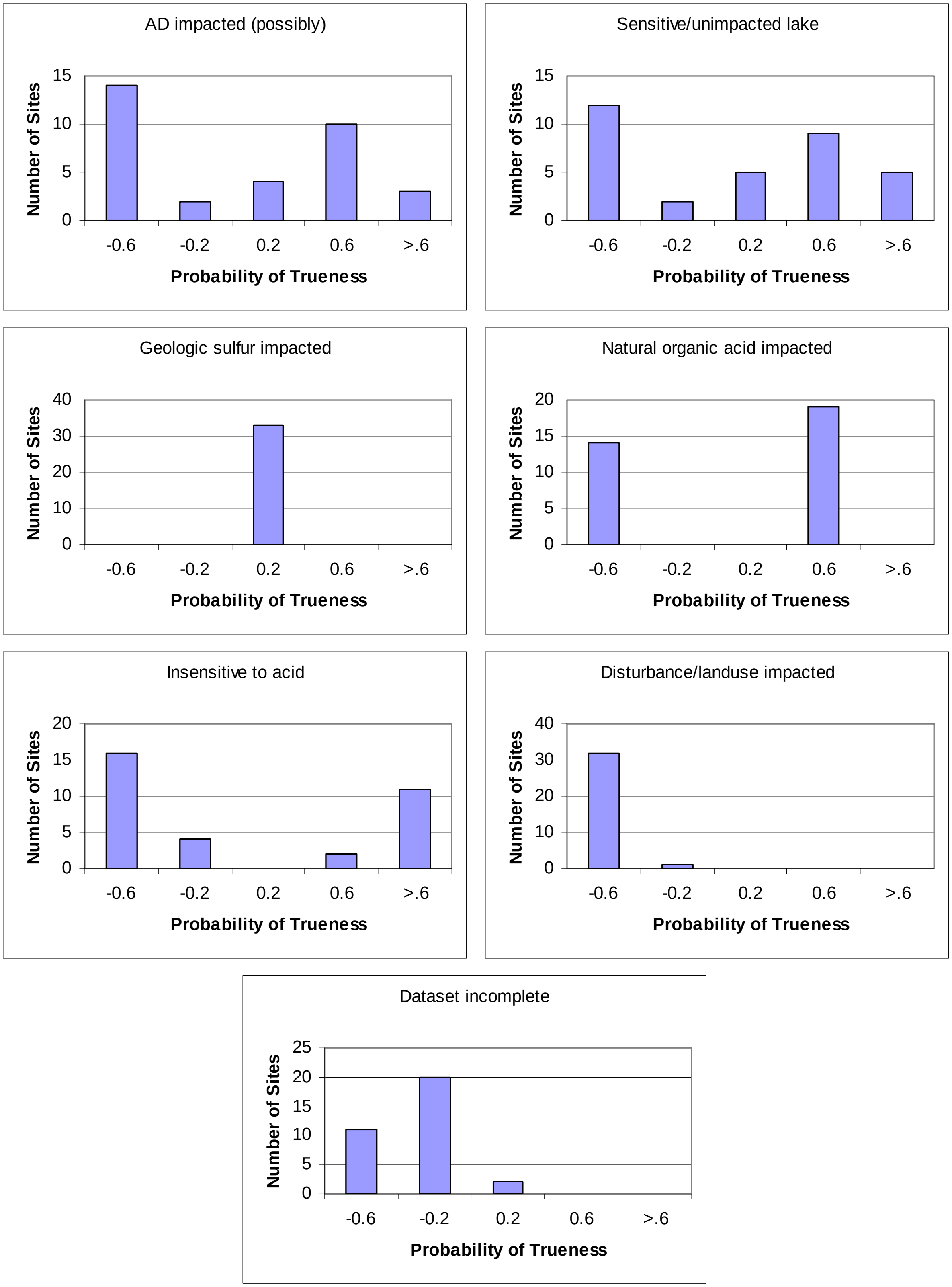


**Table 15-9: YOSE lake locations rated false in the 'Insensitive to Acid' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0016 | Ostrander Lake | YOSE0083 | May Lake |
| YOSE0025 | (No Name) | YOSE0091 | Harden Lake |
| YOSE0030 | Washburn Lake | YOSE0092 | Ten Lake Number 2 |
| YOSE0065 | Vogelsang Lake | YOSE0097 | Lower Young Lake |
| YOSE0068 | Upper Fletcher Lake | YOSE0104 | Roosevelt Lake |
| YOSE0070 | Upper Sunrise Lake | YOSE0109 | Lower McCabe Lake |
| YOSE0072 | Nelson Lake | YOSE0114 | Lake Vernon |
| YOSE0077 | Tenaya Lake | YOSE0118 | (No Name) |
| YOSE0080 | Elizabeth Lake | YOSE0120 | (No Name) |
| YOSE0081 | Lower Cathedral Lake | YOSE0121 | (No Name) |

No lakes were found to suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). In most cases, both nitrate concentrations (< 5 $\mu$eq/L) and sulfate concentrations (< 20 $\mu$eq/L) were low.

The DSS evaluates all of the locations in terms of the completeness of the input data. The 31 locations containing six or all seven inputs have relatively complete datasets. Only 2 of the locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

### *Lakes – Extreme Water Chemistry Values*

Table 15-10 lists the results of the DSS for extreme values of water chemistry parameters in lakes in Yosemite NP. Figure 15-6 graphically represents these results.

**Table 15-10: DSS Results for Extreme Lake Values - YOSE**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 13 | 11 | 0 | 14 | 16 | 31 | 11 |
| -0.59 to -0.20 | 2 | 2 | 0 | 0 | 5 | 1 | 20 |
| -0.19 to 0.20 | 5 | 6 | 33 | 0 | 0 | 0 | 2 |
| 0.21 to 0.60 | 10 | 9 | 0 | 19 | 2 | 0 | 0 |
| 0.61 to 1.00 | 3 | 5 | 0 | 0 | 10 | 1 | 0 |

The DSS result distribution for extreme lake values for the 'Acid Deposition Impacted', 'Sensitive but Unimpacted', Geologic Sulfur Impacted', and 'Natural Organic Acid Impacted' categories are largely the same as that for average lake values. This occurred because mean values for a parameter and their minimum values are the same or similar. Results at 58% of the lake locations came from a single test at that location.

The 20 lake locations listed in Table 15-9 were joined by Merced Lake (YOSE0055) are being identified as sensitive to future acidity (false in the 'Insensitive to Acid' category). Merced Lake is typical of sensitive lake locations, with low ANC (60 μeq/L), specific conductance (5 μS/cm), and base cation concentration (60 μeq/L).

A single location, Peeler Lake (YOSE0122), was found to be impacted by disturbance or land use practices (true in the 'Disturbance or Land Use Impacted' category). The DSS considered the nitrate concentration of 17 μeq/L to be too high to come from atmospheric deposition alone.

### *Streams - Average Water Chemistry Values*

Table 15-11 lists the results of the Synthesis DSS for average water chemistry values at streams in Yosemite NP and Figure 15-7 represents this data graphically.

**Table 15-11: DSS Results for Average Stream Values - YOSE**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 58 | 56 | 0 | 49 | 3 | 69 | 1 |
| -0.59 to -0.20 | 1 | 0 | 0 | 2 | 6 | 1 | 70 |
| -0.19 to 0.20 | 6 | 15 | 74 | 4 | 12 | 0 | 0 |
| 0.21 to 0.60 | 9 | 3 | 0 | 19 | 0 | 0 | 1 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 53 | 4 | 2 |

Two of the stream sites had only one data parameter for the DSS. Both sites had only a nitrate concentration. The DSS makes recommendations with certainty for these streams in the 'Acid Deposition Impacted' and 'Disturbance or Land Use Impacted' categories. One of these streams also had a value with certainty for the 'Sensitive but not Impacted' category.

Of the 74 streams for which the DSS made an assessment about acid deposition, 59 are rated as not being acid deposition impacted (false in the 'Acid Deposition Impacted' category). These streams have high buffering capability, as indicated by a high ANC (> 100 μeq/L), high specific conductance (> 15 μS/cm), and high base cation concentrations (> 175 μeq/L). Most of these streams had very low nitrate concentrations (< 8 μeq/L). Two of the streams had a nitrate concentration of greater than 800 μeq/L, concentrations too high to be from atmospheric deposition. The DSS identified 9 streams as acid deposition impacted (true in the 'Acid Deposition Impacted category') (Table 15-12). These streams are characterized by low ANC (< 50 μeq/L) and low specific conductance (< 10 μS/cm).

**Figure 15-6: Charts of DSS Results for Extreme Lake Values - YOSE**

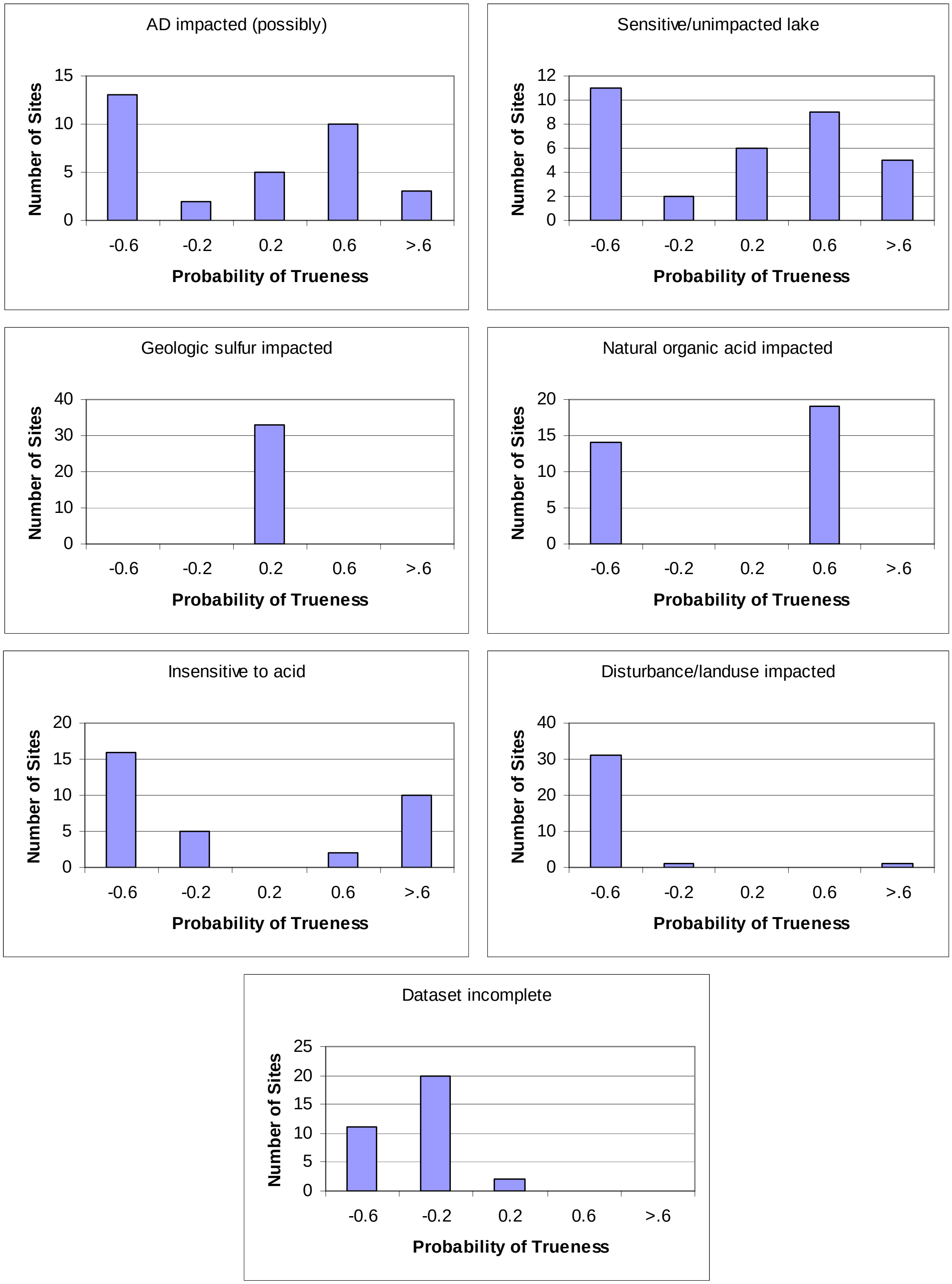


**Figure 15-7: Charts of DSS Results for Average Stream Values - YOSE**

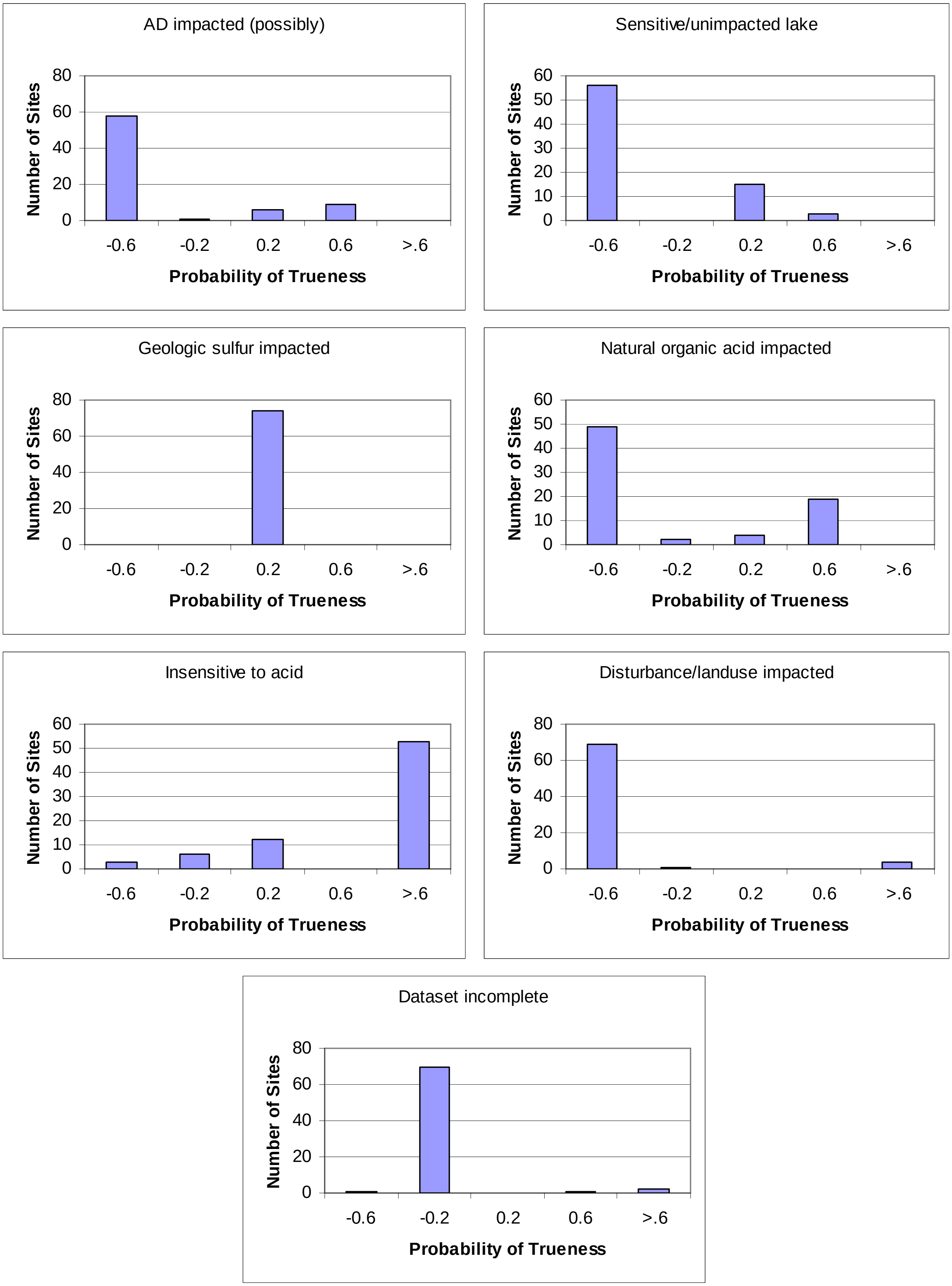


**Table 15-12: YOSE stream locations rated true in the 'Acid Deposition Impacted' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0021 | Illilouette Creek | YOSE0064 | Cathedral Fork |
| YOSE0024 | Upper Merced River | YOSE0066 | Fletcher Creek below Vogelsang |
| YOSE0026 | Merced River above Washburn Lake | YOSE0069 | Fletcher Creek above Fletcher Lake |
| YOSE0028 | Hutching Creek | YOSE0119 | Unnamed Creek |
| YOSE0056 | Merced River above High Sierra Camp | | |

The DSS classified 56 streams as not sensitive to acid deposition (false in the 'Sensitive but Unimpacted' category). This is primarily due to high ANC values (> 100 μeq/L) and high base cation concentrations (> 150 μeq/L). Only 3 stream sites were classified as sensitive to acid but not yet acid impacted (true in the 'Sensitive but Unimpacted' category): Merced River above Washburn Lake (YOSE0026), Fletcher Creek below Vogelsang High Sierra Camp (YOSE0066), and Fletcher Creek above Fletcher Lake (YOSE0069). They were identified by low ANC (≤ 50 μeq/L) and low specific conductance (≤ 6 μS/cm). The three streams were found to be true in both the 'Acid Deposition Impacted' and 'Sensitive but Unimpacted' categories.

It seems counterintuitive that a single water body can be both 'Acid Deposition Impacted' and 'Sensitive but not Impacted'. There is a reasonable interpretation of these seemingly conflicting categories. These results demonstrate that the model allows for some uncertainty in definitely lumping a lake into one category at the exclusion of all others. The potential for it to be sensitive but unimpacted is due to the fact that there still is fairly high ANC and pH; impact, if it exists, would be gauged to be moderate. The potential for it to be acid deposition impacted is due to nitrate

The DSS did not make an assessment about any of the locations in the 'Geologically Sulfur Impacted' category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS found 51 streams to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted' category). This is mainly a reflection of the high buffering capabilities of these streams, as mentioned above. Table 15-13 lists the 19 stream locations considered to be impacted by natural organic acid (true in the 'Natural Organic Acid Impacted' category). These locations have moderate levels of buffering capacity and low values of nitrate and sulfate. Their slight acidity would most likely be from organic sources.

**Table 15-13: YOSE stream locations rated true in the 'Natural Organic Acid Impacted' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0026 | Merced River above Washburn Lake | YOSE0094 | Conness Creek below Glen Aulin |
| YOSE0046 | Merced River below Sunrise Creek | YOSE0098 | Tuolumne River near Hetch Hetchy |
| YOSE0051 | Merced River above Sunrise Creek | YOSE0101 | Rancheria Creek above Rancheria Falls |
| YOSE0053 | Merced River above Merced Lake | YOSE0102 | Falls Creek above Wapama Falls |
| YOSE0057 | Merced River below Merced Lake | YOSE0106 | Lake Eleanor above Dam |
| YOSE0066 | Fletcher Creek below Vogelsang | YOSE0107 | Cherry Lake Lower Mid Point |
| YOSE0069 | Fletcher Creek above Fletcher Lake | YOSE0111 | Eleanor Creek above Lake Eleanor |
| YOSE0073 | Long Meadow Creek above Sunrise | YOSE0112 | Cherry Lake Upper Mid Point |
| YOSE0079 | Tenaya Creek above Tenaya Lake | YOSE0116 | Cherry Creek Inflow to Cherry Lake |
| YOSE0085 | Lyell Fork Inflow Tuolumne Meadows | | |

The DSS classified 53 streams as insensitive to acid (true in the 'Insensitive to Acid' category). These streams would not be affected by reasonably expected increases in acid deposition because of their high buffering capacity. These streams have high substantial buffering capacity as shown by high ANC, specific conductance, and base cation concentrations. Nine stream locations were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category) (Table 15-14). These locations had ANC values below 60 μeq/L and conductance values under 14 μS/cm.

**Table 15-14: YOSE stream locations rated false in the 'Insensitive to Acid' category.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0026 | Merced River above Washburn Lake | YOSE0106 | Lake Eleanor above Dam |
| YOSE0057 | Merced River below Merced Lake | YOSE0107 | Cherry Lake Lower Mid Point |
| YOSE0066 | Fletcher Creek below Vogelsang | YOSE0111 | Eleanor Creek above Lake Eleanor |
| YOSE0069 | Fletcher Creek above Fletcher Lake | YOSE0116 | Cherry Creek Inflow to Cherry Lake |
| YOSE0079 | Tenaya Creek above Tenaya Lake | | |

Almost all of the stream locations, 70, were found not to suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). At these 70 locations, nitrate concentrations were less than 10 μeq/L. Four streams were found to be impacted by acidity due to disturbance or land use (true in the 'Disturbance or Land Use Impacted' category): Merced River above Rancheria Flat near El Portal (YOSE0018), Merced River above Washburn Lake below Red Peak Fork (YOSE0029), Yosemite Valley Treatment Plant Effluent (YOSE0035), and Effluent from Treatment Plant near Yosemite Village (YOSE0036). All had nitrate concentrations above 15 μeq/L.

The DSS evaluates all of the locations in terms of the completeness of the input data. Of the 72 locations containing six or all seven inputs, 71 were found to have relatively complete datasets. Only 3 of the locations had less than complete datasets; the other classifications for these locations may be based on inadequate data. However, some conclusions can be based on just a single piece of data; for example, a very high ANC value can indicate that a water body is not impacted by acid precipitation and is not sensitive to it.

*Streams - Extreme Water Chemistry Values*

Table 15-15 contains the results of the Synthesis DSS of extreme water chemistry value for streams in Yosemite NP. Figure 15-8 includes graphs of the data in this table.

**Table 15-15: DSS Results for Extreme Stream Values - YOSE**

| DSS Score | Acid Deposition Impacted | Sensitive but Not Impacted | Geologic Sulfur Impacted | Natural Organic Acid Impacted | Insensitive to Acid | Disturbance or Land Use Impacted | Dataset Incomplete |
|---|---|---|---|---|---|---|---|
| -1.00 to -0.60 | 58 | 56 | 0 | 39 | 8 | 61 | 1 |
| -0.59 to -0.20 | 1 | 0 | 0 | 2 | 10 | 1 | 70 |
| -0.19 to 0.20 | 5 | 15 | 74 | 2 | 12 | 0 | 0 |
| 0.21 to 0.60 | 10 | 3 | 0 | 31 | 0 | 0 | 1 |
| 0.61 to 1.00 | 0 | 0 | 0 | 0 | 44 | 12 | 2 |

Of the 74 streams for which the DSS made an assessment about acid deposition, 59 are rated as not being acid deposition impacted (false in the ‘Acid Deposition Impacted’ category). These streams have high buffering capability, as indicated by a high ANC (> 80 μeq/L), high specific conductance (> 15 μS/cm), and high base cation concentrations (> 175 μeq/L). Most of these streams had very low nitrate concentrations (< 8 μeq/L). Two of the streams had a nitrate concentration of greater than 1500 μeq/L, concentrations too high to be from atmospheric deposition. The DSS identified 10 streams as acid deposition impacted (true in the ‘Acid Deposition Impacted category’), the 9 listed in Table 15-12 and North Fork Lyell Creek (YOSE0027). These streams are characterized by low ANC (< 50 μeq/L) and low specific conductance (< 5 μS/cm).

The DSS results for the category “sensitive but not impacted” for streams using extreme water chemistry values were the same as using mean chemistry values. Only 3 stream sites were classified as sensitive to acid but not yet acid impacted (true in the ‘Sensitive but Unimpacted’ category): Merced River above Washburn Lake (YOSE0026), Fletcher Creek below Vogelsang High Sierra Camp (YOSE0066), and Fletcher Creek above Fletcher Lake (YOSE0069). They were identified by low ANC (≤ 50 μeq/L) and low specific conductance (≤ 5 μS/cm).

The DSS did not make an assessment about any of the locations in the ‘Geologically Sulfur Impacted’ category. This is not due to any one factor, but the combination of average lake chemistry conditions that the DSS considers when deciding a rating for this category.

The DSS found 41 streams to be not impacted by natural organic acid (false in the 'Natural Organic Acid Impacted' category). This is mainly a reflection of the high buffering capabilities of these streams, as mentioned above. A total of 31 stream locations, listed below in Table 15-16, were considered to be impacted by natural organic acid (true in the 'Natural Organic Acid Impacted' category). These locations have moderate levels of buffering capacity and low values of nitrate and sulfate. Their slight acidity would most likely be from organic sources.

**Table 15-16: YOSE stream locations rated true in the 'Natural Organic Acid Impacted' category using exteme water chemistry values.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0018 | Merced River above Rancheria Flat near El Portal | YOSE0085 | Lyell Fork Inflow Tuolumne Meadows |
| YOSE0026 | Merced River above Washburn Lake | YOSE0086 | Tuolumne River above Tuolumne Meadow |
| YOSE0032 | Merced River above Pohono Bridge | YOSE0088 | Tuolumne River below Tuolumne Meadows |
| YOSE0037 | Merced River above El Capitan Bridge | YOSE0094 | Conness Creek below Glen Aulin |
| YOSE0038 | Merced River above Big Oak Flat near El Portal | YOSE0095 | Tuolumne River near Glen Aulin below Conness Creek |
| YOSE0040 | Merced River above El Capitan Bridge near Yosemite Village | YOSE0096 | Tuolumne River above Hetch Hetchy below Piute Creek |
| YOSE0046 | Merced River below Sunrise Creek | YOSE0098 | Tuolumne River near Hetch Hetchy |
| YOSE0048 | Merced River above HAPPY ISLES Bridge | YOSE0101 | Rancheria Creek above Rancheria Falls |
| YOSE0051 | Merced River above Sunrise Creek | YOSE0102 | Falls Creek above Wapama Falls |
| YOSE0052 | Merced Lake above ECHO Creek near Yosemite Valley | YOSE0103 | Eleanor Creek near Hetch Hetchy |
| YOSE0053 | Merced River above Merced Lake | YOSE0106 | Lake Eleanor above Dam |
| YOSE0057 | Merced River below Merced Lake | YOSE0107 | Cherry Lake Lower Mid Point |
| YOSE0066 | Fletcher Creek below Vogelsang High Sierra Camp | YOSE0111 | Eleanor Creek above Lake Eleanor |
| YOSE0069 | Fletcher Creek above Fletcher Lake | YOSE0112 | Cherry Lake Upper Mid Point |
| YOSE0073 | Long Meadow Creek above Sunrise | YOSE0116 | Cherry Creek Inflow to Cherry Lake |
| YOSE0079 | Tenaya Creek above Tenaya Lake | | |

The DSS classified 44 streams as insensitive to acid (true in the 'Insensitive to Acid' category). These streams would not be affected by reasonably expected increases in acid deposition because of their substantial buffering capacity as shown by high ANC, specific conductance, and base cation concentrations. Eighteen stream locations were found to be sensitive to potential changes in acidic conditions due to their low buffer capabilities (false in the 'Insensitive to Acid' category) (Table 15-17). Most of these locations had ANC values below 60 $\mu$eq/L and conductance values under 14 $\mu$S/cm.

**Table 15-17: YOSE stream locations rated false in the 'Insensitive to Acid' category.**

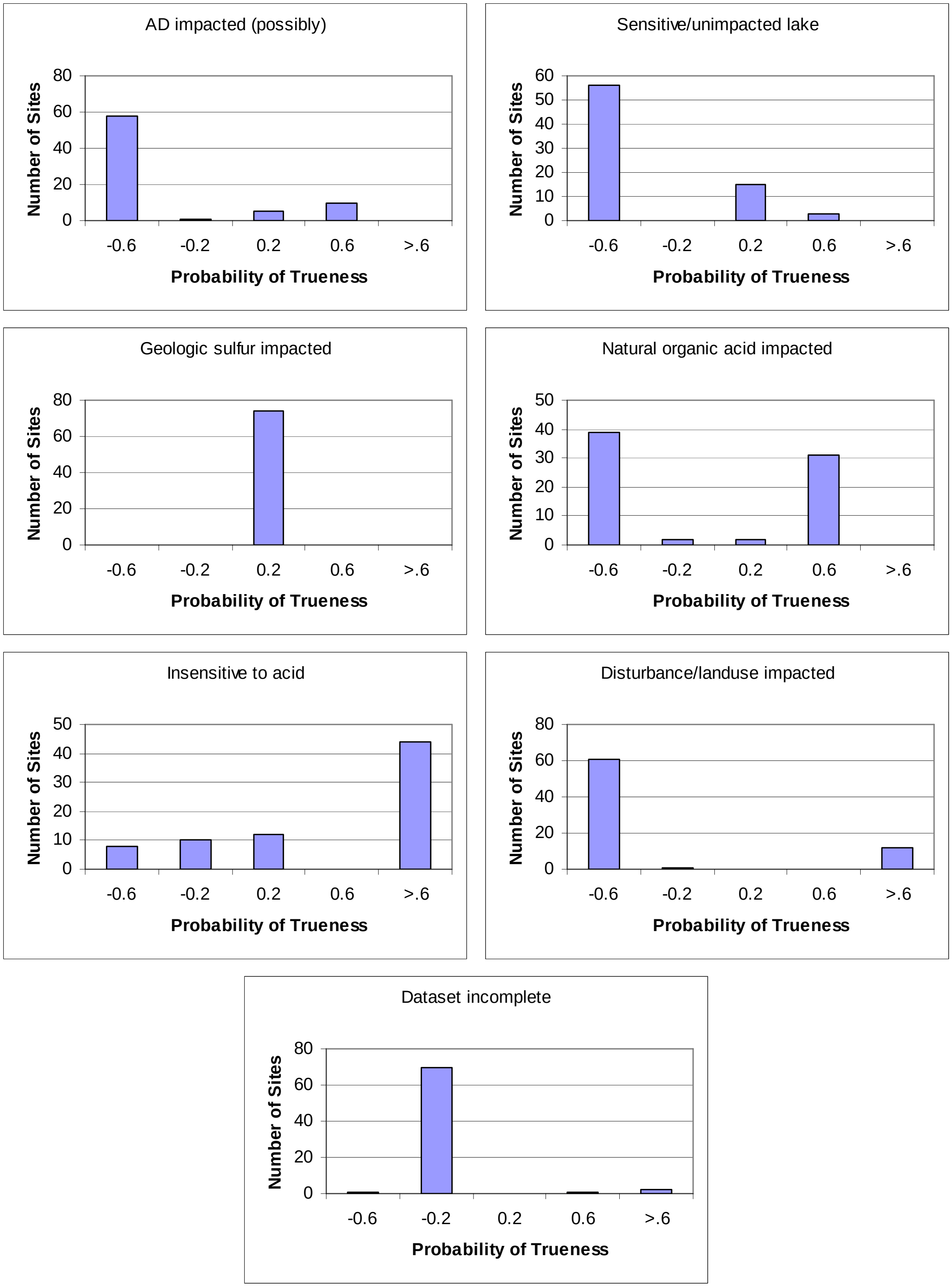
| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0018 | Merced River above Rancheria Flat near El Portal | YOSE0069 | Fletcher Creek above Fletcher Lake |
| YOSE0026 | Merced River above Washburn Lake | YOSE0079 | Tenaya Creek above Tenaya Lake |
| YOSE0038 | Merced River above Big Oak Flat near El Portal | YOSE0086 | Tuolumne River above Tuolumne Meadow |
| YOSE0040 | Merced River above El Capitan Bridge near Yosemite Village | YOSE0101 | Rancheria Creek above Rancheria Falls |
| YOSE0047 | Merced River above HAPPY ISLES Bridge | YOSE0103 | Eleanor Creek near Hetch Hetchy |
| YOSE0048 | Merced River above HAPPY ISLES Bridge | YOSE0106 | Lake Eleanor above Dam |
| YOSE0051 | Merced River above Sunrise Creek | YOSE0107 | Cherry Lake Lower Mid Point |
| YOSE0057 | Merced River below Merced Lake | YOSE0111 | Eleanor Creek above Lake Eleanor |
| YOSE0066 | Fletcher Creek below Vogelsang High Sierra Camp | YOSE0116 | Cherry Creek Inflow to Cherry Lake |

A majority of the stream locations, 62, were found not to suffer from the results of disturbance or land use (false in the 'Disturbance or Land Use Impacted' category). At these locations, nitrate concentrations were less than 10 $\mu$eq/L. Twelve streams were found to be impacted by acidity due to disturbance or land use (true in the 'Disturbance or Land Use Impacted' category) (Table 15-18). All had nitrate concentrations above 15 $\mu$eq/L.

**Table 15-18: YOSE stream locations rated true in the 'Disturbance or Land Use Impacted' category using extreme water chemistry values.**

| Location ID | Location Name | Location ID | Location Name |
|---|---|---|---|
| YOSE0018 | Merced River above Rancheria Flat near El Portal | YOSE0037 | Merced River above El Capitan Bridge |
| YOSE0019 | Merced River below El Portal | YOSE0038 | Merced River above Big Oak Flat near El Portal |
| YOSE0029 | Merced River above Washburn Lake below Red Peak Fork | YOSE0040 | Merced River above El Capitan Bridge near Yosemite Village |
| YOSE0033 | Merced River above Big Oak Flat Road | YOSE0047 | Merced River above Happy Isles Bridge |
| YOSE0035 | Yosemite Valley Treatment Plant Effluent | YOSE0048 | Merced River above Happy Isles Bridge |
| YOSE0036 | Effluent from Treatment Plant near Yosemite Village | YOSE0086 | Tuolumne River above Tuolumne Meadow |

**Figure 15-8: Charts of DSS Results for Extreme Stream Values - YOSE**



## Analysis

## Conclusion

The data for Yosemite NP used in this report tended to be older, with 87% of sites last sampled before 1990. Lakes tended to have 6 or more parameters used by the DSS but only 11 lakes (31%) have data for DOC. Eighteen lakes have mean ANC of 50 ueq/L or less. DSS results indicated potential impact from acidic deposition in about 39% of lake samples and sensitivity to acidic deposition in as many as 61% of lake samples. Impacts from natural organic acids were judged to be possible in 19 lake samples (58%) but only 11 of these samples included data for DOC, so results should be considered tentative. Impacts from disturbance or land use seem unlikely in all lakes having data. Geologic sulfur does not seem to impact any of the lakes sampled.

Streams in Yosemite NP tend to have 6 or more parameters used by the DSS (71% of samples). DSS results indicated potential impact from acidic deposition in about 11% of stream samples and sensitivity to acidic deposition in as many as 11% of stream samples. Impacts from natural organic acids were judged to be possible in 19 stream samples (22%) but only 1 of these samples included data for DOC, so results should be considered tentative. Impacts from disturbance or land use seem likely in 4 streams. Geologic sulfur does not seem to impact any of the lakes sampled.

- *For the Acid Impacted and Sensitive/Unimpaired categories, the DSS returned a ‘true’ value for these locations; for the Insensitive to Acid category, the DSS returned a ‘false’ value.
- **”Last Sampled” refers to the last documented sample from the Horizon Report used in this analysis.

# Chapter 16 : Summary and Conclusions –

This study used the Horizon Database of surface water chemistry and the Decision Support System, expert system software, to determine potential problems in eight national parks. The software is calibrated for the Cascade Mountains, Central and Southern Rocky Mountains, New England, and the Sierra Nevada. The DSS evaluates data for lakes and streams with respect to various types of potential environmental impact or conditions and assigns a probability between +1 and -1 that an impact is true or false for those data. In this study we arbitrarily divided these probabilities into quintiles for ease of presentation. The DSS results can best be understood as starting at a value of 0 for data that are inconclusive as to whether an impact (or condition) is likely or not likely. Values progressively more negative indicate that impact (or condition) is unlikely whereas more positive values indicate that impact (or condition) is likely the case. Thus, the absolute value of the DSS result is an indicator of how confident the DSS is for given data.

The water quality data required for the Aquatic Chemistry DSS and used to classify lakes in parks comes from the NPS Baseline Water Quality and Analysis Reports. Because Horizon Systems Corporation in conjunction with NPS's Servicewide Inventory and Monitoring Program and the NPS's Water Resources Division (WRD) gathered the data, these reports are known as Horizon reports. The goal of these reports is "to provide descriptive water quality information in a format useable for park planning purposes."

The data extracted from the Horizon reports is summary data, including both mean values and extreme values. Conclusions drawn from using the mean data are likely to underestimate the extent of problems such as acid rain impacts or mine drainage impacts. In addition to using mean values this study brackets the true situation regarding impacts by using a worst-case combination of the extreme values. This worst-case combination would include a site's lowest values for parameters that measure the protection of the water from impact (ANC, sum of base cations, and specific conductance) and its highest values for parameters that contribute to acidification (sulfate, nitrate, and DOC). The worst-case combination would also include minimum pH values, an indication of acidity, and minimum chloride values, to report the lowest fraction of sulfate may have come from neutral sea spray as opposed to sulfuric acid.

Of the 2953 sample locations identified in the Horizon reports for the nine parks in this analysis, 21% of them had no data for any of the parameters used by the DSS. Another 27% had one or two of these parameters. Only 5% of locations had all of the parameters used by the DSS. When the DSS does not have enough data to make a decision, it places a high degree of uncertainty on that site. It is difficult to come to any conclusions about locations that have such uncertainty.

Another issue concerns the infrequency of sampling. Often, sampling occurred frequently at a location for temperature but infrequently for other parameters. Many results contain data from one or two samples. For example, of the 1200 locations that contain alkalinity data, 60% of them contain only one measurement. In these cases, the result is 'extreme' values that are the same as the mean values.

It appears that much of the data contained in the Horizon reports reviewed for this analysis is outdated. Some of the reports were issued up to a decade ago. Sampling occurred at most of these locations in the 1970s and 1980s. In fact, of the 2620 locations that have recorded data, 77% were sampled before 1990, and 51% were sampled before 1980. The last samples from a few locations came from the 1930s. The condition of these waters has probably changed over the past 15 years, much less over 20 to 30 years.

The most time-consuming step in this study was conversion of data into consistent units for input into the DSS. A more consistent set of parameters and units is greatly needed. Also, some data stored as being for different sites may be from multiple samples from single sites but stored as different sites. Thus, consistent definition of site locations is needed.

The DSS results depend on both the data input and the calibration for various environmental impacts and conditions for the different parks studied. Review of DSS results indicates that calibration probably is reasonable for acid deposition effects and sensitivity to acid deposition. The DSS probably overestimates impacts from natural organic acids if data are not available for DOC. This needs to be kept in mind in considering results because few samples included data for DOC. The DSS probably underestimates the impacts of geologic sulfur; this results from the need to definitively separate the effects of atmospheric sulfate from natural watershed sources. Some fine-tuning for individual parks would be helpful for this category of impact.

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# Chapter 18 - List of Figures

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